

R. E. LANGENHEIM, JR.
DEPT. GEOL. UNIV. ILLINOIS
254 N.H.B., 1301 W. GREEN ST.
URBANA, ILLINOIS 61801

R. E. LANGENHEIM, JR.
DEPT. GEOL. UNIV. ILLINOIS
254 N.H.B., 1301 W. GREEN ST.
URBANA, ILLINOIS 61801

A stratigraphic study of beach features on the southwestern shore of Lake Michigan: new evidence of Holocene lake level fluctuations

Curtis E. Larsen



1985
ENVIRONMENTAL GEOLOGY NOTES 112

Illinois Department of Energy and Natural Resources
STATE GEOLOGICAL SURVEY DIVISION

COVER PHOTO: This photograph of a forest bed exposed by wave erosion south of Southport Park, Kenosha, WI, was taken by Phil Sander in 1973. The forest bed overlies unoxidized gray till and is overlain by nearshore lacustrine sand and dune sand.

Drafting: Pat Whelan

Larsen, Curtis E.

A Stratigraphic Study of Beach Features on the Southwestern Shore of Lake Michigan: New Evidence of Holocene Lake Level Fluctuations. — Champaign, Ill. : Illinois State Geological Survey, 1985.

31 p. ; 28 cm. — (Environmental geology notes; 112)

1. Lake Michigan—Water level. I. Title. II. Series.

Printed by authority of the State of Illinois/1985/2000

A stratigraphic study of beach features on the southwestern shore of Lake Michigan: new evidence of Holocene lake level fluctuations


Curtis E. Larsen

U. S. Geological Survey
Reston, Virginia

1985
ENVIRONMENTAL GEOLOGY NOTES 112

ILLINOIS STATE GEOLOGICAL SURVEY
Morris W. Leighton, Chief

Natural Resources Building
615 East Peabody Drive
Champaign, Illinois 61820



Digitized by the Internet Archive
in 2012 with funding from
University of Illinois Urbana-Champaign

<http://archive.org/details/stratigraphicstu112lars>

ABSTRACT	1
INTRODUCTION	1
PREVIOUS RESEARCH	5
Outlet and crustal-rebound control of Holocene lake levels	5
Extent and timing of postglacial rebound	7
Holocene climatic history	7
NIPISSING AND ALGOMA STAGES: STRATIGRAPHIC SECTIONS	9
Kenosha-Waukegan area	9
North Shore Channel-Chicago River area	12
Michigan City-Beverly Shores, Indiana	15
Summary: Nipissing and Algoma stages	17
POST-ALGOMA LAKE LEVELS	18
SYNTHESIS OF LATE HOLOCENE FLUCTUATIONS OF LAKE MICHIGAN	21
CONCLUSIONS	25
REFERENCES	26
APPENDIX: DATED STRATIGRAPHY	28

FIGURES

1 Beach ridge progradation sequence and study area	2
2 Middle Holocene wave-cut bluff exposed at Winthrop Harbor	3
3 Graphic lithologic logs from transect between Kenosha and Waukegan	4
4 Paleosol exposed by wave erosion south of Kenosha	9
5 Longitudinal profile showing stratigraphy along Barnes Creek	10
6 Intersection of Nipissing II terrace with middle Holocene bluff line at Barnes Creek	12
7 Nipissing stage lacustrine deposition along North Shore Channel, Chicago River	13
8 Depositional shoreline features of Chicago area	14
9 Upper marsh silt exposed at Beverly Shores	16
10 High-energy beach deposits at Beverly Shores	17
11 Fluctuations in late Holocene lake levels in southern Lake Michigan	18

TABLES

1 Calibrated radiocarbon dates	22
2 Comparison of climatic changes during the last 2000 years with southern Lake Michigan levels	24

ACKNOWLEDGMENTS

This research was begun under the auspices of the Illinois State Geological Survey when I was a graduate student at the University of Chicago in 1973. With the help of Charles Collinson my interest in Lake Michigan has expanded to include the late glacial and isostatic uplift history of the Lake Michigan basin. This manuscript was reviewed by Byron Stone and Carl Koteff, who provided helpful comments. It was approved for publication by the U. S. Geological Survey on August 12, 1983. Final preparation of the report would not have been possible without the help of Ardith K. Hansel who guided the manuscript and drawings through the final editorial process in Illinois.

ABSTRACT

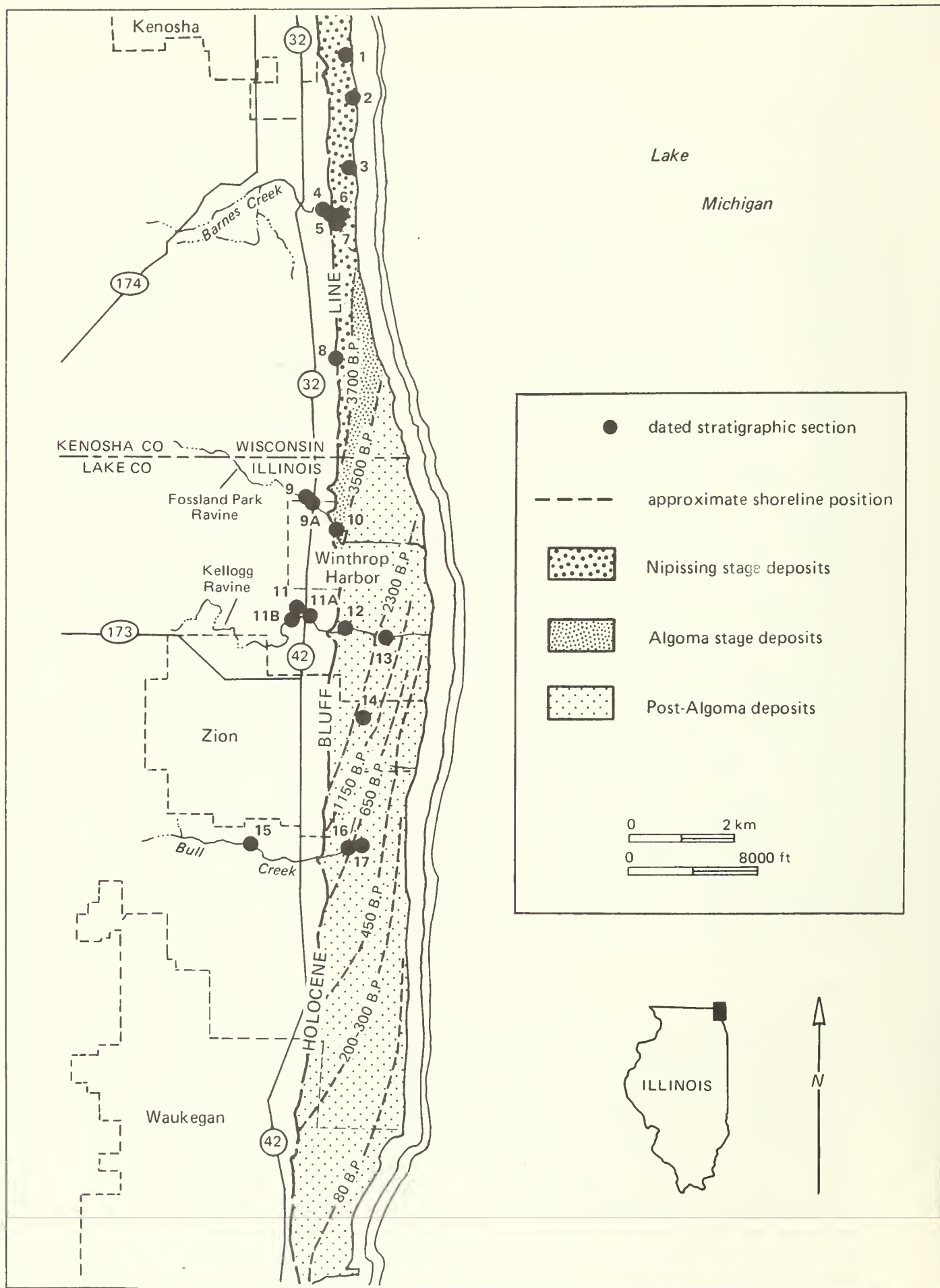
This study of a beach ridge complex along the southwestern shore of Lake Michigan provides new evidence of long-term trends in water level fluctuations of Lakes Michigan and Huron that are not discernible in the short, 125-year historic record of measured lake level changes. Radiocarbon age control of lake terraces and other beach features provided by dates from buried peat and fossil wood indicates that during the past 2,000 years lake levels were markedly higher and lower than present levels for periods on the order of centuries. This suggests that historically recorded levels, considered high by modern standards, may represent a relatively low cycle on a naturally fluctuating trend. Study results thus have important implications for engineers and hydrologists concerned with planning and construction along the lake shore.

The established geological history of the Great Lakes region recognizes three prominent lake stages in the postglacial Upper Great Lakes—the Nipissing stage (5,500–3,800 B.P.), the Algoma stage (3,800–2,500 B.P.), and modern Lakes Michigan and Huron (2,500 B.P. to present). The Nipissing stage was initiated when differential isostatic uplift raised northern outlet channels above southern outlets, causing the lakes to rise and drain through preexisting late glacial outlets at Chicago and Port Huron, Michigan. Incision of the Port Huron outlet about 3,800 B.P. caused the levels of the lakes to drop to those of the subsequent Algoma stage; the Chicago outlet was abandoned. Renewed incision of the Port Huron outlet about 2,500 B.P. caused a final drop to the present level of Lakes Michigan and Huron.

Results of the present study provide for a more detailed interpretation of these changes and indicate that conspicuous fluctuations of Lake Michigan have occurred during the past 2,000 years—a period previously recognized as one of relatively stable levels. The Nipissing and the Algoma stages of the lakes have been defined here as high fluctuations of Lake Michigan separated by subsequent periods of low lake level. An early Nipissing stage fluctuation (Nipissing I) attained an altitude of 183 m about 4,500 B.P. A second Nipissing stage fluctuation (Nipissing II) reached an altitude of 180.5 m about 4,000 B.P. Temporal agreement with Holocene neoglacial and pollen records suggests that the Holocene levels of Lakes Michigan and Huron were climatically related to changes in water volume in these lake basins. Such fluctuations appear to have been superimposed on the differential isostatic uplift of the region and suggest that Nipissing and Algoma stage levels could not have been controlled solely by episodic incision of the outlet channel at Port Huron.

INTRODUCTION

Fluctuations in levels of the Great Lakes have been a research topic since the early 19th century. Sporadic records of lake levels for Lake Huron and Lake Erie were kept as early as 1819 (Horton, 1927), but continuous records have been maintained by the U.S. Army Corps of Engineers only since 1860. From 1860 to the present, recorded changes in levels have ranged from seasonal fluctuations to fluctuations having possible periodicities of 8 to 20 years, attributed to climatic factors (Liu, 1970); the maximum variation between high and low levels has been approximately 2 m. In contrast, the geologic record shows greater changes in lake levels during the late Pleistocene and the Holocene—an interval of about 12,000 years. Levels in the southern part of Lake Michigan have been as high as 20 m above present levels (Leverett and Taylor, 1915) and as low as 118 m below those of the present levels (Hough 1955, 1958).



ISGS 1985

FIGURE 1. Beach ridge progradation sequence and study area.

Little evidence for postglacial changes in lake level has been found along the southwestern shore of Lake Michigan. As early as 1908, J.W. Goldthwait noted that this region had been exposed to active wave erosion, which had destroyed many of the diagnostic postglacial landforms. In contrast, along the northern shore of Lake Michigan, isostatic rebound has been rapid enough to uplift and preserve Holocene-age beach features at altitudes well above the present level of the lake.

This study is centered on a beach ridge complex along the southwestern shore of Lake Michigan between Kenosha, Wisconsin, and Waukegan, Illinois (fig. 1). Littoral sediment transport in this location has been from north to south as a result of onshore winds having a maximum fetch from the northeast. A progression of curvilinear beach ridges, separated by interridge marshes, was formed by the combined action of wind and waves. These ridges acted as a protective barrier against shore erosion and preserved coastal landforms and stratified deposits dated from middle Holocene times to the present. A depositional buffer 1.5 km wide separates a well-defined Holocene bluff line (fig. 2) from the active shoreline of Lake Michigan.

Interridge marshes contain varying thicknesses of organic sediments useful for dating depositional events. The beach ridge complex is also incised by four streams that drain the adjacent uplands. These stream valleys preserve Holocene alluvial fills that document a record of stream-mouth deposition associated with changes in base level. A progradation sequence for the area can be defined on the basis of six important cores from interridge marshes and a historic data base. Radiocarbon dates from basal peat that overlies beach deposits limit the age of deposition of underlying and successively landward beach ridges.



FIGURE 2. Middle Holocene wave-cut bluff exposed at Winthrop Harbor, Illinois. Note intersection of beach ridge complex with base of the bluff (SW $\frac{1}{4}$ SE $\frac{1}{4}$ NE $\frac{1}{4}$ NW $\frac{1}{4}$ Sec. 10, T 46 N, R 12 E, Main Street, Winthrop Harbor).

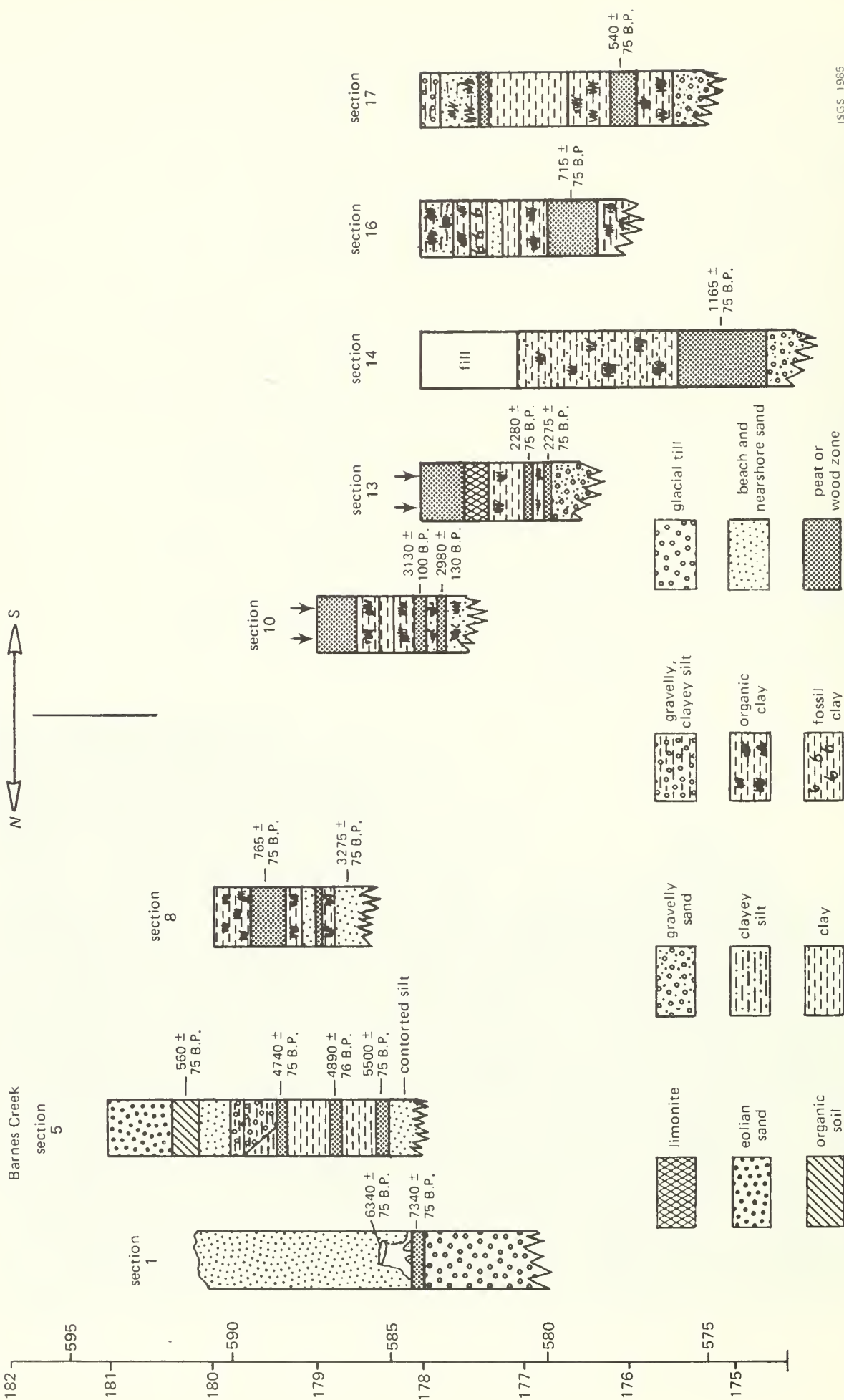


FIGURE 3. Graphic lithologic logs from a north-south transect between Kenosha, Wisconsin, and Waukegan, Illinois. (Refer to fig. 1 for section locations.)

The part of the beach ridge complex north of the Illinois-Wisconsin boundary is directly related to deposition during the Nipissing and Algoma stages of the upper Great Lakes (5,500–2,500 B.P.); the more extensive area of beach ridges to the south is post-Algoma (2,500 B.P. to present) (fig. 1). A drop in altitude from 181 m in the north to 178 m in the south corresponds to a long-term lowering of lake level. A more recent age limit can be placed on the southern extreme of the complex on the basis of the 1872 shoreline position, obtained from U.S. Lake Survey charts. An archeological survey of the entire beach ridge area showed that Woodland age archeological sites, predating European and American settlement, cover parts of the beach ridge complex. No aboriginal archeological evidence exists south of a ridge zone in the southern part of the complex shown as the shoreline labeled 200–300 B.P. in figure 1. This abrupt absence of archeological sites probably indicates displacement of the native population by settlers in the late 18th and early 19th centuries (Thwaites, 1902) and provides additional chronological control on the progradation sequence.

Although this study focuses on the Kenosha-Waukegan area, it also incorporates related stratigraphic evidence from Chicago, Illinois, and Michigan City, Indiana. Because this region has undergone only slight isostatic uplift, the effect of isostatic rebound on lake level change is minimal here. This study presents a record of intermediate scale changes in lake level for Lake Michigan and Lake Huron—the Holocene fluctuations from 8,000 B.P. to the present.

The record of lake level fluctuation points to long-term trends in the water volume of Lake Michigan and Lake Huron that are not discernible in the short, 125-year historic record used by engineers and hydrologists. The well-dated prehistoric record of lake level change obtained from geological studies suggests that the water levels recorded historically represent a period of relatively low lake levels. This period followed an extended interval of higher levels that ended about the time of Euro-American settlement of the region. The detailed geologic record presented in this study combines the records of past and present, allowing engineers and planners to consider lake-oriented design, planning, and construction against a framework of naturally occurring lake level changes.

PREVIOUS RESEARCH

Outlet and crustal-rebound control of Holocene lake levels

The established geologic history of Lake Michigan and Lake Huron is a product of detailed fieldwork conducted early in this century by a number of researchers. Leverett and Taylor (1915) have presented the most complete history of the lakes; although revised by later workers (Bretz, 1955; Hough, 1955, 1958, 1963; Lewis, 1969, 1970), Leverett and Taylor's model has remained essentially unchanged. Glacial ice fronts, differential isostatic rebound, and outlet channels have all been recognized as factors in the lake level changes. Hough (1958) presented and reviewed much of the early work and presented a synthesis of the geology of the Great Lakes region. His model, as modified by Dorr and Eschman (1970), Lewis (1969, 1970), and Evenson et al. (1976), is summarized here:

The Lake Michigan basin was occupied by two proglacial lakes. The earliest of these, Lake Chicago, was ponded behind the Valparaiso and Tinley moraines south of Chicago. Overflow of the lake incised a channel (known as the Chicago outlet) through the moraine. Prominent wave-cut terraces and depositional features found at approxi-

mately the same altitude are evidence that the altitude of this channel controlled the level of early Lake Chicago and gave rise to the Glenwood stage of the lake (195.2 m).

Further incision of the outlet to an altitude of 189.1 m (ostensibly because of increased water volumes diverted from contemporaneous proglacial lakes Saginaw and Whittlesley in the Lake Huron and Lake Erie basins, respectively) caused a concomitant drop in Lake Chicago to the Calumet stage. This stage, like the Glenwood stage, was also marked by erosional and depositional landforms. Continued incision of the Chicago outlet lowered the spillway to a bedrock surface at an altitude of 184.5 m. A stillstand, referred to as the Toleston stage, resulted at this altitude. The outlet was abandoned after the retreat of Woodfordian ice about 12,500 B.P. Lower northern outlets were then exposed, allowing the lake to drain eastward to the Gulf of St. Lawrence. The resulting water level, sometimes referred to as the Kirkfield stage, fell as low as 172.3 m. This low was synchronous with the growth of the Two Creeks forest, dated at about 11,800 B.P.

Subsequent readvance of Two Rivers ice into the Lake Michigan basin blocked the northern outlets of Lake Chicago and gave rise to proglacial Lake Algonquin about 11,500 B.P. The level of this lake was controlled by the altitude of the Chicago outlet at 184.5 m. Lake Algonquin is thought to have reoccupied beaches of the former Toleston stage of Lake Chicago. As the Two Rivers ice margin retreated into Ontario, the northern outlets were reopened, causing lake levels to drop substantially.

A lowering of the levels of these lakes culminated with the Chipewewa and Stanley low stages of Lake Michigan and Lake Huron (Hough, 1958). According to Hough, lake altitudes during these extremely low stages dropped to 70.2 m (Lake Michigan) and 60 m (Lake Huron) as the lakes drained north and eastward to the Gulf of St. Lawrence—via the North Bay-Ottawa River outlet—across isostatically depressed areas of Ontario. This period marks the beginning of the postglacial history of Lakes Michigan and Huron, the central focus of this study.

Rapid postglacial uplift of the upper Great Lakes region raised the North Bay-Ottawa River outlet, allowing the lakes in the Superior, Michigan, and Huron basins to rise and drain through the more southerly spillways at Chicago and at Port Huron, Michigan. The level of the three upper lakes then returned to the previous levels of the Toleston stage of Lake Chicago, and Lake Algonquin at 184.5 m (605 ft). This postglacial period, characterized by a relatively high lake level, is referred to as the Nipissing stage of the three upper Great Lakes. The Nipissing stage consisted of two phases, Nipissing I and II. Nipissing I, according to Lewis (1969), occurred between 5,500 and 4,700 B.P., when drainage took place via three outlets: North Bay-Ottawa River, Chicago, and Port Huron. This was the period of maximum transgression of the Nipissing stage. Lewis claims that the Nipissing II phase was between 4,700 and 3,700 B.P. and was marked by a slight drop in level. The North Bay-Ottawa River was closed during this phase because of continued uplift. Drainage in the Nipissing phase continued through the outlets at Port Huron and Chicago.

At approximately 3,700 B.P., incision of the Port Huron outlet allowed Lakes Michigan and Huron to fall to altitude 181.5 m. The Chicago outlet was abandoned at this time and the lower outlet at the

south end of Lake Huron reopened. The stabilized lake level at the new altitude of the Port Huron outlet was termed the Algoma stage of Lakes Michigan and Huron. Lake Superior became a separate lake when differential uplift, coupled with the falling levels of the lower lakes, exposed a bedrock sill in the St. Mary's River channel, maintaining lake level at 182.5 m. According to Hough (1958, 1963), modern Lakes Michigan and Huron were formed about 2,500 B.P. when continued incision of the Port Huron outlet caused the Algoma stage level to fall to the mean historic level of approximately 176.9 m. These lakes have been maintained near this level by the threshold of the present St. Clair River at Port Huron.

Extent and timing of postglacial rebound

Lakes Michigan and Huron can be considered as an entity for hydrologic purposes. The Straits of Mackinac allows unrestricted flow between the lakes, and both lakes share a common outlet to the lower Great Lakes through the St. Clair River at Detroit. This drainage did not develop until the late Holocene, however, when structural changes in the basin modified the outlet patterns and warped the shape of the basin itself. These basin changes were the result of postglacial isostatic rebound occurring after the removal of vast thicknesses of glacial ice.

Goldthwait (1908) and Leverett and Taylor (1915) showed that most uplift took place along the northern shores of Lakes Michigan and Huron. Erosional beach terraces of similar age were observed to be upwarped to progressively greater elevations from south to north. Farrand (1962) showed that uplift in the Great Lakes is closely related to continuing uplift in the Hudson's Bay region. Such uplift is viewed as an exponential function decreasing with time (Washburn and Stuiver, 1962; Farrand, 1962; Ten Brink, 1974); the uplift was most pronounced soon after deglaciation and has been gradually decreasing until the present. This concept has been discussed and expanded by Andrews (1970), and Walcott (1970). Shoreline features in the southern parts of Lakes Michigan and Huron, however, appear to indicate minimal uplift. Two prominent Holocene terraces (Nipissing, ca. 5,000 B.P., and Algoma, ca. 3,700 B.P.) are noticeably uplifted only north of Green Bay, Wisconsin, and Traverse Bay, Michigan. This zone of flexure has become known as the "Nipissing hinge line." Areas south of this line are referred to as the zone of "horizontal" or "no deformation" (Leverett and Taylor, 1915).

This "zone of horizontal" is well suited for detailed study of relative lake-level changes during the Holocene. Although slight historic uplift has taken place south of this zone, Clark and Persoage (1970) showed that the southern Lake Michigan area experienced only minimum uplift over the past century, and is the least deformed part of the lake basin. Thus, postglacial lake-level changes can be determined without extensive correction for postglacial uplift.

Holocene climatic history

The effect of post-Pleistocene climate on lake levels has been largely overlooked in studies of the Great Lakes. Leverett and Taylor's (1915) model assumes that static lake levels and periodic episodes of postglacial isostatic rebound account for raised beach features. Hough (1958) believed that Holocene climatic fluctuations did occur, but were not significantly different from those recorded over the past century. Consequently, climatic changes were thought to produce only minor fluctuations in lake level. These minor

fluctuations were superimposed upon significant lake level changes produced by physical changes in the shape of the basin and the threshold altitudes of outlets. This view has since been questioned by Larsen (1973, 1974) and Fraser et al. (1975) on the basis of recent paleoclimatic research.

Although climatic trends differ somewhat on a regional basis, broad trends can be delineated for the postglacial period by means of pollen analyses (Davis, 1969; Wright, 1966, 1968). Such broad trends appear to be similar over the northeastern portion of the United States. Pollen data indicate that climate warmed towards the middle of the Holocene but cooled gradually thereafter.

The broad climatic trends are well established, but do not reflect short-term variations that may have affected the levels of Lakes Michigan and Huron during the Holocene. Webb and Bryson (1972), however, have inferred shorter term climatic changes from multivariate analysis of present-day pollen distributions and from Holocene pollen records. Their pollen analysis from a bog west of Lake Michigan shows several short-term fluctuations superimposed on the broad long-term climatic pattern. Significant cool periods occurred around 500, 1,250, 1,750, and 3,000 B.P.

More recent paleobotanical research from the upper Great Lakes region shows a similar array of short-term changes in climate. Swain (1978), in a study of northern Wisconsin lake sediments, showed well-defined moist periods at about 400, 1,000, and 1,900 B.P. and conspicuously dry periods at about 900 and 1,500 B.P. Bernabo (1981) has indicated a similar record of temperature changes preserved in pollen cores from the northern lower peninsula of Michigan. Cool periods occurred at about 500 and 1,200 B.P., corresponding generally to dates for the moist intervals described by Swain. Bernabo also indicated a discrete period of warm, mild temperatures between 1,600 and 2,200 B.P.

Neoglacial activity reported in geologic studies by Denton and Karlen (1973), Curry (1969), Benedict (1973), and Goldthwait (1966), may also be related to climatic changes during the Holocene. Denton and Karlen suggested that periods of worldwide glacial expansion occurred between 5,800 and 4,900 calendar years B.P. and between 3,300 and 2,400 calendar years B.P. in Alaska, the western conterminous United States, and Sweden. More recent glacial expansion took place about 1,150, 750, and 200 B.P. Curry's (1969) work from the Sierra Nevada of California indicates periods of expansion corresponding to those recorded by Denton and Karlen. Benedict (1973) documents periods of cirque glaciation between 5,800 and 4,000 calendar years B.P. and a period of less extensive but more recent glacial activity between 1,750 and 500 B.P. in the Colorado Front Range. Goldthwait (1966) pointed to Holocene glacial advances in Alaska generally corresponding to those presented by Denton and Karlen (1973), but having glacial maxima during the past few centuries.

Cool, moist climatic intervals recorded by Swain (1978) and Bernabo (1981) over the past 2,000 years correlate chronologically with the periods of glacial expansion presented by Denton and Karlen for the same period. Similarly, Denton and Karlen's early period of glacial expansion (5,800-4,000 calendar years B.P.), as well as those periods noted by Benedict and Goldthwait, took place at about the same time as the Nipissing- and Algoma-stage transgressions of the postglacial Great Lakes. These similarities suggest that lake level changes of the Great Lakes during the Holocene may also have been climatically influenced.

Lewis (1969, 1970) has attempted to revise the Hough/Leverett and Taylor model through dating of stratigraphic sections on Manitoulin Island

and in the Port Huron region of Lake Huron. These revisions have not, however, produced the detail necessary for defining shorter term trends in lake levels. This study examines these questions.

NIPISSING AND ALGOMA STAGES : STRATIGRAPHIC LOCALITIES

Kenosha-Waukegan area

Immediately south of the Kenosha city limit, shore erosion in 1973 exposed a 2-m stratigraphic sequence of crossbedded nearshore sands overlying 0.5 m of weathered glacial till (fig. 3, section 1). Figure 4 is a photograph of this sequence. A soil developed on the till supported a forest growth of oak and elm (Sander, 1969; Schneider et al., 1977) indicated by macrobotanical remains. Whereas radiocarbon dating of organic silt from the paleosol gave an age of $7,370 \pm 75$ B.P., wood from trees in growth position at an altitude of 178 m is dated at $6,340 \pm 300$ B.P. and $5,315 \pm 75$ B.P. This sequence shows a transgression of the lake to a level greater than the maximum altitude of the surface of the overlying nearshore sand (180 m). A transgression of this magnitude and age is generally viewed as marking the beginning of the Nipissing stage and associated crustal rebound in the Lake Michigan-Huron basin. The forest growth and weak soil formation is associated with the lower lake levels of the Chippewa Stage and mark the entry of an oak-hickory forest association into the southern Lake Michigan area. An exposure (fig. 1, section 2) shows as much as 3 m of finely bedded eolian sand overlying the nearshore sand body. Here, a thick, organic-rich soil that developed on the surface of the nearshore sand is dated at 780 ± 75 B.P., providing a minimum age limit on the initiation of eolian activity. Transported wood fragments incorporated in crossbeds of the nearshore sand 2 km south of the forest bed (fig. 1, section 1) yielded a $6,350 \pm 140$ B.P.



FIGURE 4. Paleosol exposed by wave erosion south of Kenosha, Wisconsin. This soil, developed in glacial till, is dated at $7,340 \pm 75$ B.P. Oak and elm tree stumps found in growth position on this paleosol have been dated at $6,340 \pm 300$ B.P. and $5,315 \pm 75$ B.P. This former land surface is covered by cross-bedded nearshore sands of the Nipissing transgression. (Photo by Phil Sander)

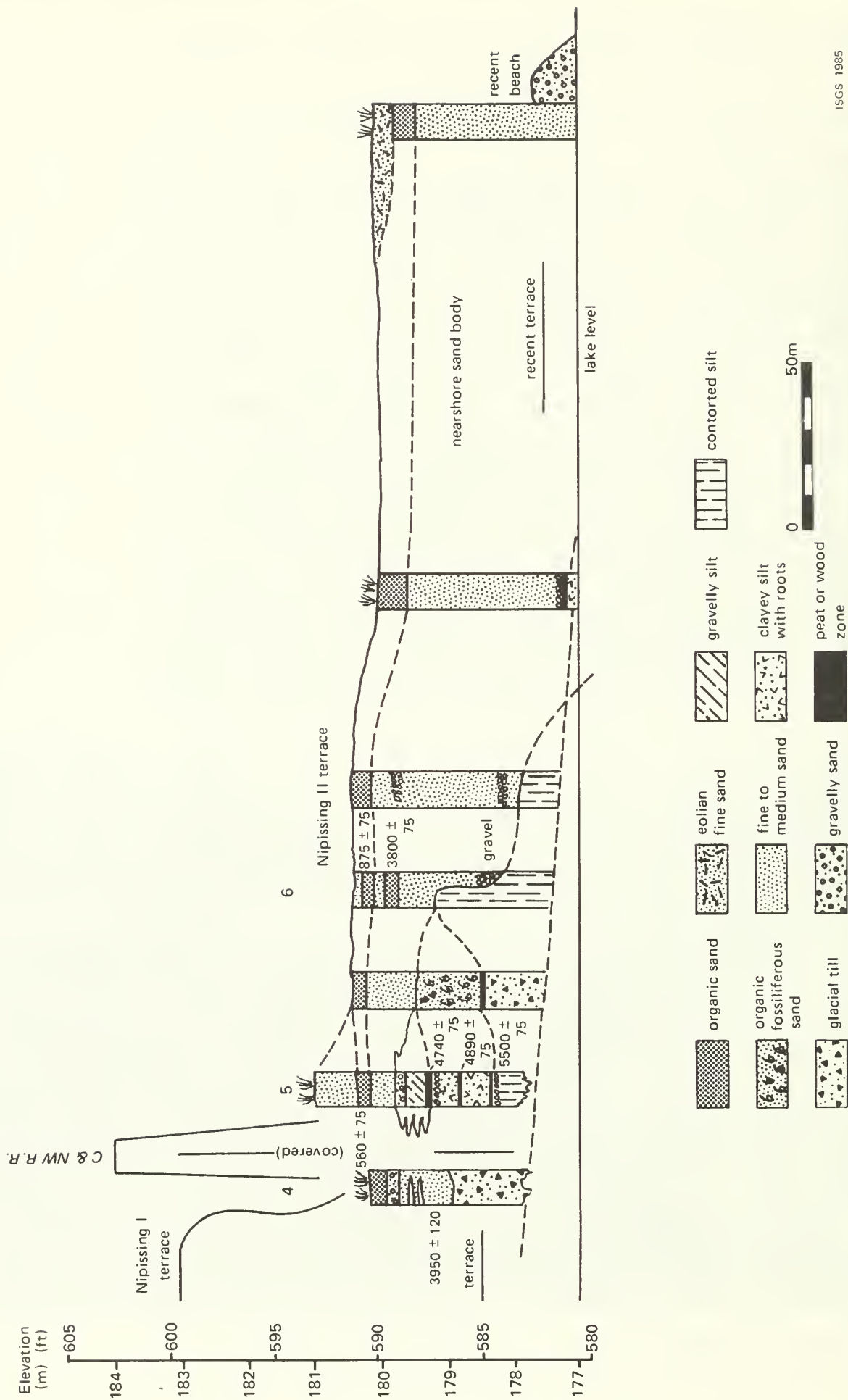


FIGURE 5. Longitudinal profile showing stratigraphy along Barnes Creek, Wisconsin.

date (fig. 1, section 3); this date is comparable with that on *in situ* wood from the forest bed at section 1.

Three kilometers south of Kenosha, the Nipissing-age nearshore sand has been eroded by Barnes Creek, providing a 500 m discontinuous exposure showing stratigraphic relationships (fig. 5). Nearshore sands were deposited on a surface of contorted lacustrine silt and glacial till. Marshes formed in depressions on the previous land surface (figs. 3 and 5, section 5), between $5,500 \pm 75$ B.P. and $4,740 \pm 75$ B.P. The surface of the marsh was later incised by a stream channel prior to its final burial by the nearshore sand body (fig. 5). Organic sand from a paleosol developed on the nearshore sand in this location is dated at 560 ± 75 B.P. This soil is associated with a Late Woodland period archeological site of similar age (Vander Leest and Halmo, 1980). Two discontinuous organic layers within the upper part of the nearshore sand body have been dated 875 ± 75 B.P. and $3,800 \pm 75$ B.P. (figs. 1 and 5, section 6). The uppermost and younger of the two is broadly contemporaneous with the organic soil dated at 780 ± 75 B.P. (fig. 1, section 2). The date of the lower organic zone, however, further restricts the time limit for the formation of the surface on the nearshore sand. Lake transgression thus took place between 6,340 B.P. and 3,800 B.P. but apparently did not reach a maximum altitude until after 4,740 B.P. This date does not correspond with that of Lewis' (1969) Nipissing I phase, which was assigned to the 5,500-to-4,700 B.P. interval. A dated section west of the nearshore sand body limits the age of the termination of this first transgression (figs. 1 and 5, section 4). Organic marsh sands at this location overlie an eroded surface of silty glacial till. The lowermost organic layer was dated at $3,950 \pm 120$ B.P., an age similar to that determined for the organic zone in section 6 to the east. Here, however, stream incision to an altitude of at least 179 m apparently occurred before these marshes were formed.

The ^{14}C -dated sections indicate a rise in lake level related to the Nipissing stage of the upper Great Lakes that attained an altitude of 180 m (590.1 ft) between 4,740 B.P. and 3,950 B.P. This age is chronologically equivalent with the Nipissing II phase defined in Lake Huron by Lewis (1969). The altitude for Nipissing II terraces in southern Lake Huron is 184.5 m, whereas that of the well-defined feature at Kenosha is only 180.5 m. Sediments and landforms of a discrete Nipissing I age are not exposed in the Barnes Creek area. Morphologic evidence does exist, however, for a higher erosional terrace at 183 m. Figure 6 shows the intersection between the surface of the depositional terrace at 180 m and the erosional surface at 183 m. A lack of exposure and a lack of organic material prohibit firm correlation of this surface with Lewis' Nipissing I phase.

No beach deposits younger than 3,800 B.P. are apparent on the surface of the nearshore sand at Barnes Creek; this indicates the absence of a subsequent higher Algoma-stage transgression above altitude 180 m. Although Algoma-stage beach features from southern Lake Huron have been identified at altitude 180.5 m by Lewis (1969), these features are not easily identifiable at Kenosha, even though the 180.5-m surface of the nearshore sand body suggests an altitudinal correlation. Radiometric age control suggests that a Nipissing-II-phase lake formed the surface of this sand body. This event clearly corresponds to Lewis' Nipissing II phase and its age is limited by the $3,800 \pm 75$ B.P. date on the organic sand at Section 6.

Evidence for a lake-level stand at the Algoma stage level, about 1 m below the Nipissing II levels, is found near Carol Beach, Wisconsin (figs. 1 and 3, section 8). Here, a core shows the beginning of marsh growth at altitude 178.8 m about $3,275 \pm 75$ B.P. This date provides a minimum

age limit on the deposition of underlying beach deposits of the Algoma stage. Overlying peat is dated at 765 ± 75 B.P. Crests of nearby beach ridges attain altitudes of about 180 m, suggesting a lake level lower than the Nipissing II surface at Barnes Creek.

A core from an interbeach-ridge marsh near Winthrop Harbor, Illinois (figs. 1 and 3, section 10) shows a similar stratigraphy of alternating peat and clayey silt on the surface of older beach sediments. Here, two basal peat layers at altitudes 177.8 and 177.6 m have been dated at $3,130 \pm 100$ and $2,980 \pm 130$ B.P., respectively. These layers indicate marsh sediment accumulation postdating the Algoma stage, and a water table closely related to lake level at about 178 m. Figure 1 shows a contemporaneous lakeshore as near as 500–600 m to the east. Overlying clayey silt indicates flooding of the marsh when lake levels increased after 2,980 B.P. The clay and silt, in turn, are overlain by peat, evidence of a return to active marsh conditions. The basal peat dates shown in figures 1 and 3 date the end of the Algoma stage of Lakes Michigan-Huron.

North Shore Channel-Chicago River area

During the early part of the century, Holocene lake and marsh deposits were exposed in excavations for the North Shore Channel of the Chicago River. Detailed stratigraphic descriptions recorded by Baker (1920) included faunal collections consisting primarily of pelecypods and gastropods. Wood from some of Baker's stratigraphic exposures was also saved. In the course of the present study, Baker's original locations were visited to resample critical sections. Most stratigraphic sections were reexposed. A section north of the intersection of Foster Avenue and the North Shore Channel (fig. 7) shows a lowermost thin unit of marsh silt and clay (177.0 m-



FIGURE 6. Intersection of the Nipissing II depositional terrace (180.5 m) with the middle Holocene bluff line at Barnes Creek, Wisconsin. Note erosional terrace feature on wooded slope. This feature, at altitude 183 m, probably represents the Nipissing I level of the lake. Stratigraphic section at Section 4 (figs. 1, 3) is in right foreground.

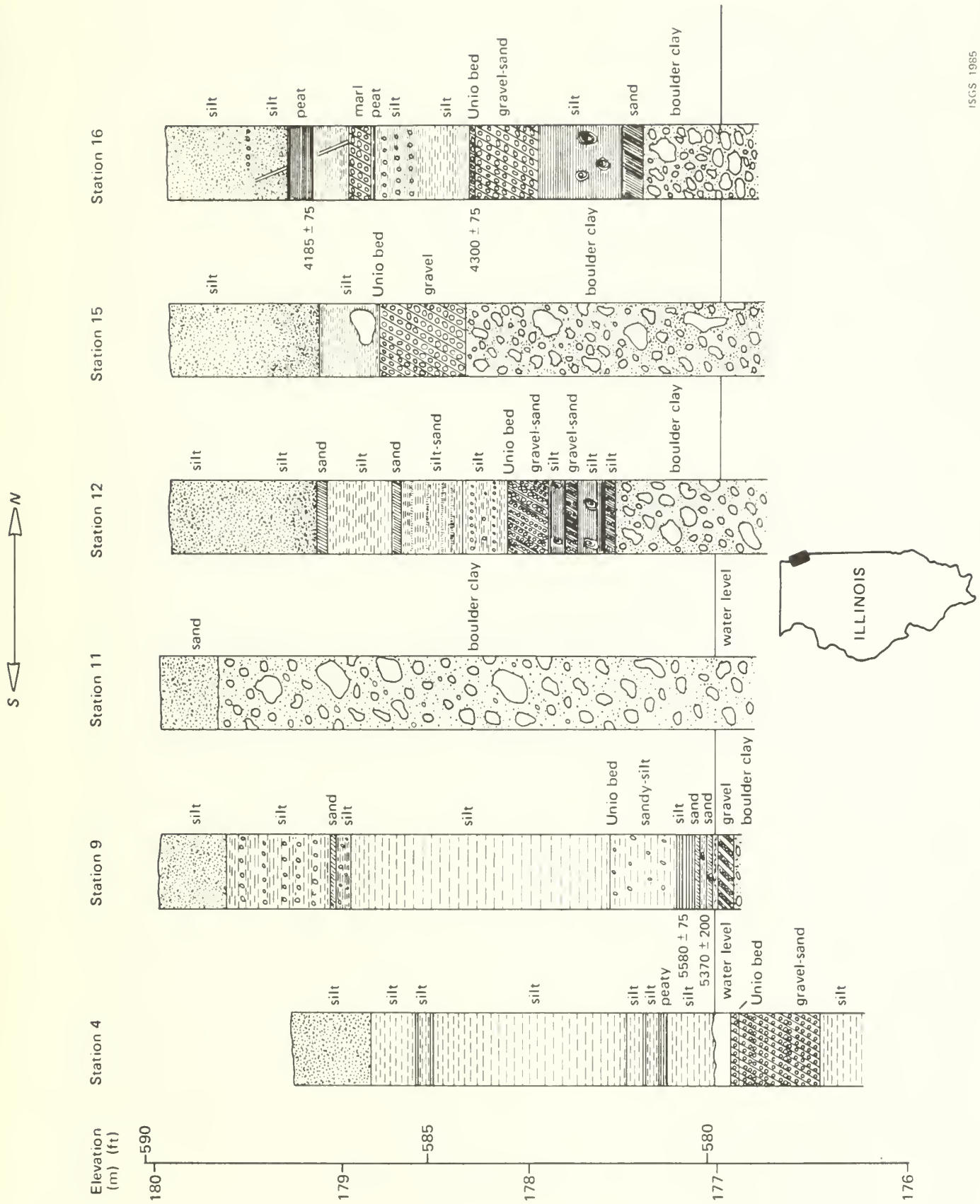
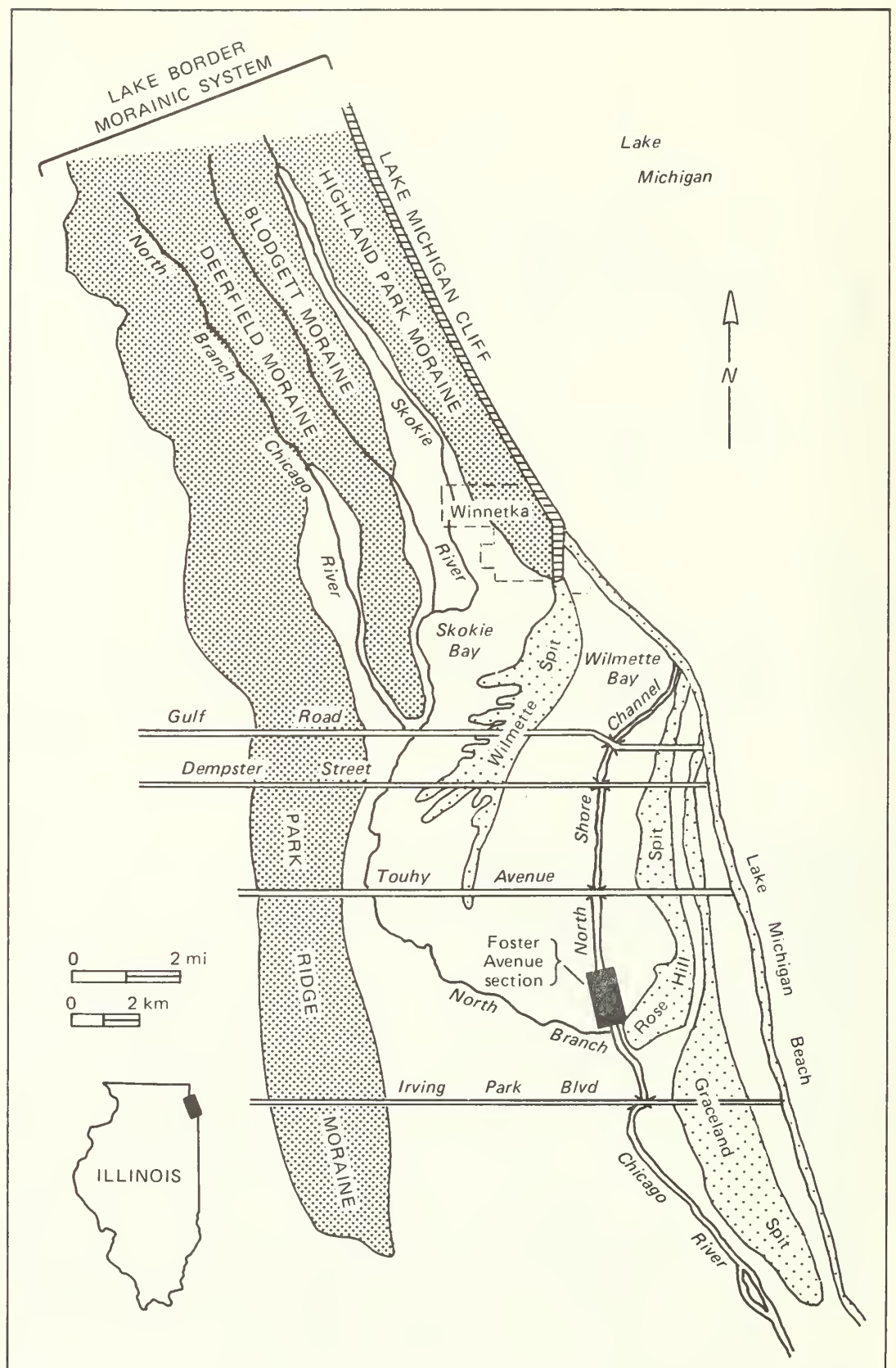


FIGURE 7. Nipissing stage lacustrine deposition along North Shore Channel, Chicago River, north of Foster Avenue (from Baker, 1920, Plate I). Note: Station numbers are from Baker's study (p. 26-57); 14C dates are from this study.



ISGS 1985

FIGURE 8. Depositional shoreline features of the Chicago area (adapted from Bretz, 1955).

177.3 m). Wood from this deposit was dated by Morris M. Leighton (Willman and Frye, 1970) at $5,370 \pm 200$ B.P. and in this study at $5,580 \pm 70$ B.P. Gray to brown medium-grained sand and gravelly sand 30 cm thick overlie the marsh deposit. The surface of this bed ranges in altitude from 177 m to 179 m and is marked by a concentrate of pelecypod shells dated at $4,300 \pm 75$, $4,550 \pm 70$, and $4,690 \pm 90$ B.P.

Baker's (1920) paleoecological analysis of the fauna from the sand unit indicates a fluvial environment—a hard rocky bottom with clear, running water at depths ranging from 1.5 to 6 m. Species indicative of this environment include *Elliptio crassidens*, *Amblema peruviana* and *Pleuroblema coccinea magnalacustris*. Gray silty clay, 30 cm thick, overlies this molluscan zone; its upper surface, about 178 m in altitude, is fairly level. The Nipissing gastropod *Goniobasis livescens* (Miller et al., 1979) is present in this silty clay. The upper part of the silty clay unit is oxidized and contains thin lenses of peat in shallow depressions. These peat lenses are dated at $4,185 \pm 75$ B.P.

The Foster Avenue section (fig. 7) is somewhat similar to the Barnes Creek section (fig. 5). Marsh deposits at 177 m show that the lake level was near or below this altitude between 5,370 and 5,580 B.P. A subsequent higher lake level established an outlet to the Illinois River valley via the Chicago River (Bretz, 1955; Hough, 1958); this outlet channel supported a locally rich population of riverine mussels. The age of this transgression indicates the Nipissing stage, but because fauna were found over a wide depth range (177.8 to 185 m), it was not possible to reconstruct the actual water plane. This part of the outlet channel was also affected by the deposition of the contemporaneous Graceland spit sequence to the east (fig. 8). Shelter from wave action may have led to rapid fine-sediment deposition in marshes in the lee of the spit. The level of the lake dropped below altitude 178.2 m by 4,185 B.P.; this date is consistent with Barnes Creek dates and indicates that a somewhat lower lake level preceded the Nipissing II phase.

Michigan City-Beverly Shores, Indiana

A 3.2-km outcrop of postglacial deposits west of Michigan City, Indiana was exposed during low lake levels between 1961 and 1962. These were described by Winkler (1962), who showed that the base of the exposure at altitude 176.8 m contained contorted clay, which he interpreted as evidence for periglacial conditions. A zone of compressed wood at the surface of the contorted clay marked a contact with an overlying gray silt-clay indicative of a lakeshore marsh environment. The wood marking the contact between the two units was dated at $6,350 \pm 200$ B.P., and wood from the surface of the marsh was dated at $4,690 \pm 200$ B.P. (Gutschick and Gonsiewski, 1976). A very pale brown lacustrine sand 60 cm thick overlay the gray silt clay, and was, in turn overlain by a second, but discontinuous, bed of silt-clay. Wood from this upper clay yielded a date of $5,475 \pm 250$ B.P. Abundant grass fragments and the presence of the ostracod genus *Cyclocypris* in the unit suggested a marsh environment to Winkler (1962).

An exposure at the foot of Central Avenue in Beverly Shores, Indiana, shows only the uppermost clay-silt (fig. 9) dated at $4,690 \pm 200$ B.P. This is overlain by crossbedded, coarse- to medium-grained nearshore sand that reaches an altitude of 182.5 m. Gutschick and Gonsiewski (1976) point out that wood from the discontinuous bed at the Michigan City section may have been transported because wood from the underlying silt at Central Avenue is younger. Above the sand is a 30-cm bed of oxidized, gravelly sand

showing imbricated beach-gravel clasts (fig. 10). Three to 4 m of fine-grained eolian sand overlies this high-energy succession of beds. A paleosol formed in this sand at 184 m is dated at $3,710 \pm 200$ B.P., providing a limit to deposition of the beach gravels at 182.5 m (Gutschick and Gonsiewski, 1976). The paleosol indicates a pause in eolian sediment supply and the growth of vegetation, probably related to increasing soil moisture.

The exposures at Michigan City and Beverly Shores show a vertical succession of stratified units similar to those at Barnes Creek and Chicago. A transgression, younger than 6,350 B.P., inundated a marsh and allowed deposition of a nearshore sand. Lake level then remained stable or dropped below altitude 178 m, allowing the formation of additional intermittent marshes. Similar marsh deposits at Chicago dated at 5,370 and 5,580 B.P.

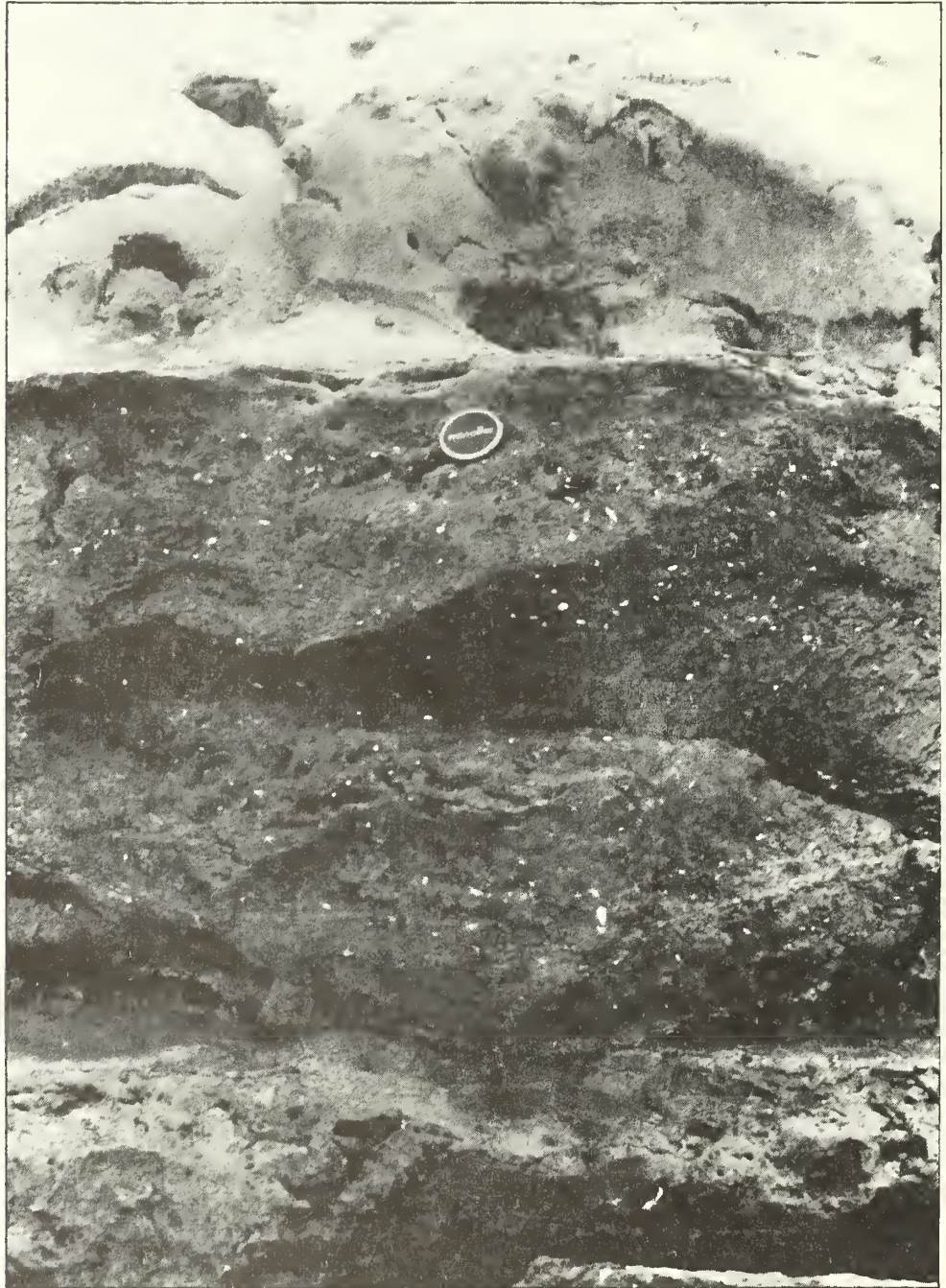


FIGURE 9. Upper marsh silt exposed at Central Avenue, Beverly Shores, Indiana, dated at $4,690 \pm 200$ B.P. by Gutschick and Gonsiewski (1976). Note the conspicuous gastropod fauna present.

suggest a regression to a point lower than altitude 177 m. A subsequent transgression of the lake to at least altitude 182.5 m is indicated by high-energy beach deposits. The altitude of these deposits is similar to that of the erosional terrace at Barnes Creek, thought to have been formed during the Nipissing I phase. The paleosol developed in eolian sand at 3,710 B.P. is similar in age to the paleosols at Barnes Creek, Wisconsin that postdate the 180.5 m terrace. Thus, two distinct lake levels at 182.5 m and 180.5 m occurred between 5,500 and 3,710 B.P.

Summary: Nipissing and Algoma stages

Three stratigraphic sections from the southern Lake Michigan Basin and in the area of minimal equal uplift present a pattern of lake-level change corresponding to the Nipissing and Algoma stages of Lakes Michigan-Huron. From the Chippewa and Stanley low stages, lake level rose to at least 177.7 m, about 6,350 B.P. This unnamed lake stage receded to at least 177.2 m, allowing for the formation of marshes in the 5,370- to 5,475-B.P. interval. During a later rise to an altitude of 183 m, a marsh at Barnes Creek was inundated at 179.3 m about 4,740 B.P., but lake level had receded to below 178.1 m by 4,185 B.P. Molluscan faunas at Chicago represent the transgression of the Nipissing I phase between 4,690 and 4,300 B.P. On the basis of the stratigraphic evidence presented, this transgression left beach deposits below terrace surfaces at 180 and 183 m in altitude, 1.5 m to 3 m lower than the Nipissing-stage terraces at Port Huron, Michigan. The high



FIGURE 10. High-energy beach deposits at altitude 182.2 m at Central Avenue, Beverly Shores, Indiana. This deposit is immediately overlain by 3 to 4 meters of eolian sand.

level of the lake that reached 183 m at Michigan City is equivalent to Lewis' Nipissing I phase; however, it did not reach maximum level until about 4,500 B.P.

A regression of the lake to below 179 m after the Nipissing I peak is indicated by stream incision to that altitude at Barnes Creek, but subsequent ponding and marsh growth occurred at this altitude after 3,950 B.P., probably indicating a subsequent rising lake level and aggradation along tributary streams. This rise left an erosional terrace at 180.5 m at Barnes Creek and is equivalent to Lewis' Nipissing II phase; the event was relatively brief because soil had begun to form on the terrace at Barnes Creek by 3,800 B.P.

Beach ridges at altitude 180 m at Carol Beach, Wisconsin, are attributed to the Algoma stage. Peat formation in interrIDGE marshes began by 3,275 B.P. By 3,055 B.P., Algoma-stage beach deposits were deposited at 177.8 m at Winthrop Harbor, Illinois; overlying marsh growth was probably related to a fluctuating lake level near or below this altitude. Beach ridges with crests at about 180 m in the vicinity of Carol Beach represent a somewhat lower Algoma stage level of the lake. They are lower in altitude than the Algoma terraces in southern Lake Huron described by Hough (1958) at 181.5 m and by Lewis (1969) at 180.5 m. The Algoma-stage level was certainly lower than the crests of beach ridges at Carol Beach. Therefore the Algoma level is assumed to have been no higher than 179 m. This stage ended in southern Lake Michigan by 3,055 B.P.

POST-ALGOMA LAKE LEVELS

The change in altitude between Nipissing/Algoma and younger beach features in the Kenosha-Waukegan beach ridge complex is abrupt. For example, ridges south of Winthrop Harbor appear only locally above the surface of presently active marshes (about 178 m) for a distance of 8 km. Near Waukegan, at the southern end of the complex, ridges capped by dunes reach greater heights (about 181 m). A continuous sequence of ridges throughout the area is locally covered by younger marsh deposits (Fraser and Hester, 1974; Hester and Fraser, 1973). On the basis of the apparent succession of marsh deposits over beach deposits, a period of relatively lower lake level and beach ridge deposition followed the Algoma stage but was, in turn, succeeded by somewhat higher levels. Such changes are difficult to document stratigraphically in the beach ridge complex itself but become clearer when viewed in conjunction with other data from the area.

Cores from the marshes present a record of alternate flooding and drying but do not provide an adequate basis for determining actual water depths. Peat deposits, however, suggest groundwater levels, which, in turn, may be tentatively related to changes in lake level. Thick clay and slightly silty clay indicate lacustrine transgression. Fluvial sand from streams draining the glacial and lacustrine deposits of the uplands to the west provide additional information on lake history.

Four permanent streams cross the beach ridge complex (fig. 1). During a period of climate-related high relative lake level between 1971 and 1975, interrIDGE marshes flooded and caused ponding at the mouths of these streams, at locations now as much as 1.6 km from the shoreline. Local deposition of fluvial sediments has also been observed; the stream gradients and deposits at the mouths are apparently graded to the present lake level. Three prominent alluvial terraces are preserved near the mouths of three of the four streams examined. Radiocarbon dates show that terraces 2.4 m,

1.4 m, and 0.75 m above the existing streambeds are post-Nipissing in age. These three terraces and nearby marsh deposits are evidence of apparent high relative lake levels as much as 2.4 m above the present level, whereas lower than present levels are indicated by a record of peat deposits in the interridge marshes.

Marsh and fluvial evidence for lake level change are discussed here in order of decreasing age.

- At Camp Logan (figs. 1 and 3, section 13), peat and organic sand at altitudes of 176.7 to 176.9 m overlie older beach deposits. The peat, dated at $2,275 \pm 75$ B.P. and $2,280 \pm 75$ B.P., indicates the growth of marsh vegetation near lake level. The peat is overlain by 40 cm of gray organic lacustrine silt that indicates an increase in water depth in the marsh. A 30-cm limonite crust at the surface of the organic silt shows a period of oxidation related to drying of the marshes, a lower water table, and consequently, a potentially lower lake level. The entire sequence is covered by 10 cm of organic silt.

- A paleosol containing well-developed pedogenic horizons is preserved in the alluvial fill of Bull Creek (fig. 1, section 15). This organic A-horizon, dated at $1,750 \pm 75$ B.P., indicates a period of active soil formation during a period of nondeposition in the alluvium of Bull Creek. A 1-m-thick sequence of silt and gravelly silt above the paleosol indicates a subsequent increase in alluviation. Wood from within alluvium along Kellogg Ravine (fig. 1, section 11B), dated at $1,580 \pm 75$ B.P. marks the onset of approximately 2 m of alluvial deposition above the modern streambed of this tributary.

- A similar alluvial deposit younger than 1,750 B.P. has been preserved in the terraces of a tributary stream flowing through Fossland Park, Winthrop Harbor, Illinois (figs. 1 and 7, section 9). Two paleosols are exposed here in a sequence of fluvial silty sand and sandy silt. The lower paleosol, found at altitude 184.2 m (1 m above the present streambed), is dated at $1,320 \pm 75$ B.P. It is overlain by 0.5 m of silty sand upon which a second organic zone, dated at $1,015 \pm 75$ B.P., has formed. This upper paleosol, in turn, is buried by silty, fine sand that constitutes the surface of the terrace. These organic horizons mark periods during which alluviation did not take place and may coincide with stabilization of base level or periods of stream incision. Subsequent burial of the lower paleosol and formation of the upper paleosol indicate a period of alluviation between 1,320 and 1,015 B.P., during which streams aggraded to a point about 1.5 m above the present base level. Alluviation to about 1.7 m reoccurred sometime after 1,015 B.P.

- Peat overlying beach deposits at the base of an interridge marsh adjacent to Shiloh Boulevard (figs. 1 and 3, section 14) is dated at $1,165 \pm 75$ B.P. This organic layer is found at altitude 174.7 to 175.5 m, 2.2 m below the present lake level. As much as 1.5 m of clayey silt containing organic material overlies this peat, indicating subsequent flooding of marshes. Although the thickness of peat may have changed through compaction and compression resulting from subsequent placement of a roadfill over the marsh, the basal altitude is considered an indication of the approximate maximum level of the lake at the time of deposition.

- At the base of Kellogg Ravine (fig. 1, section 12) a 0.8-m deposit of sandy silt and silty sand, dated at $1,105 \pm 75$ B.P. and $1,195 \pm 75$ B.P., indicates that an aggrading stream buried an interridge marsh at 179.3 m. Up to 2 m of alluvial deposits has been found along Kellogg Creek. This

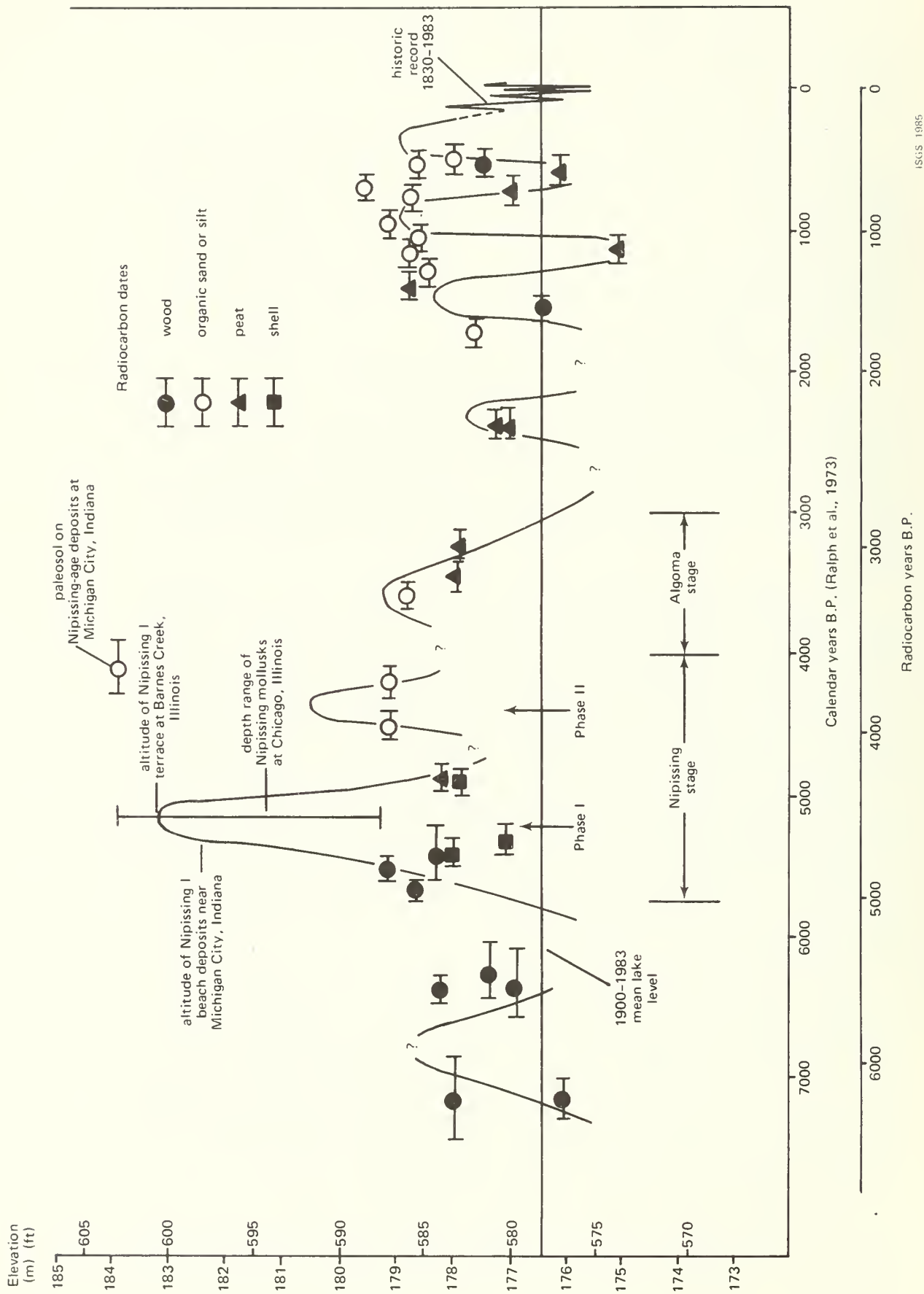


FIGURE 11. Fluctuations in late Holocene lake levels in southern Lake Michigan.

alluviation possibly marks the end of an extensive period during which lake levels were lower than present and the beginning of a period characterized by levels as much as 2 m above present levels.

- Similar peat deposits from the bases of interridge marshes along Wadsworth Road (fig. 3, sections 16 and 17), point to other lake level changes. Here, a peat formed over the underlying beach ridges has been dated from 715 ± 75 to 540 ± 75 B.P., an indication that the lake level was as much as 0.5 m below the present level for an extended period. Overlying deposits of clay and silty clay in both of these cores indicate subsequent flooding. This drop in lake level is also suggested by the interruption of an alluvial sequence along Kellogg Ravine (fig. 1, section 11A), where a paleosol overlying an archeological site is dated at 790 ± 75 B.P. This soil was subsequently buried by 0.3 m of alluvial sand. Formation of a terrace 2 m above the modern stream along Kellogg Creek (fig. 1, section 11) followed deposition of branches and leaves dated at 385 ± 75 B.P. This terrace formation, indicating upward growth of the flood plain, suggests a change in base level. A similar condition is noted at Fossland Park (fig. 1, section 9A) where alluvium has buried branches dated at 440 ± 75 B.P.

The composite record of marsh stratigraphy and alluvial deposits indicates periods during the late Holocene when lake level was both above and below the present level. The relative magnitude of lake-level changes can be determined on the basis of the altitudes of these deposits and the thickness of alluvium above modern streams. Clearly, this evidence of the fluctuating lake level during the post-Algoma stage of Lakes Michigan-Huron calls for a revision of the existing models that attribute control of post-Algoma levels of the lake primarily to the threshold depth of the St. Clair River, which has maintained lake level at an altitude of about 177 m over the past 3,000 years (Hough, 1958). The presence of longer term fluctuations in lake level of as much as 2 m above and below the present level suggests that other significant variables have interacted in the hydrological system.

SYNTHESIS OF LATE HOLOCENE FLUCTUATIONS OF LAKE MICHIGAN

Figure 11 shows a composite record of relative lake-level changes over the past 7,000 years, based on radiocarbon dates of material collected in the southern Lake Michigan area (table 1). The overall pattern of lake level changes shows general trends related to the Nipissing and Algoma stages of the upper Great Lakes (Hough, 1958, 1963). The fluctuating post-Algoma lake levels reported in this study are inconsistent with those of earlier interpretations suggesting that lake level stability was maintained by the altitude of the Port Huron outlet. For example, the fluctuations in late Holocene lake level documented by the Kenosha-Waukegan beach ridge complex cannot be easily explained by episodic erosion of outlets. The timing and magnitude of the fluctuations do not support Hough's (1958) assumptions that Holocene climatic changes were similar to those recorded during the past century. It seems more likely that significant Holocene climatic changes, interacting with isostatic rebound and outlet erosion, played a major role in forming the observed landforms. Earlier researchers concentrated on shoreline features (such as the Nipissing and Algoma terraces of Lakes Michigan and Huron), and thus missed the significance of a broadly fluctuating lake level. Figure 11 gives a revised interpretation of lake level fluctuations in the middle and late Holocene.

Table 1. Calibrated radiocarbon dates

Lab. No.*	Date (B.P.)	Material	Corrected date (Ralph et al., 1973)	Reference
ISGS-187	7,370 ± 75	Organic silt		Fraser et al., 1975
ISGS-185	6,350 ± 200	Wood	7,050	Larsen, 1974
I-363	6,350 ± 140	Wood	7,050	Winkler, 1962
W-1017	6,340 ± 300	Wood	7,050	Sander, 1969
ISGS-928	5,580 ± 70	Wood	6,420	This paper
ISGS-313	5,500 ± 75	Wood	6,360	This paper
I-362	5,475 ± 250	Wood	6,350	Winkler, 1962
W-425	5,370 ± 200	Wood	6,220-6,280	Willman & Frye, 1970
ISGS-189	5,315 ± 75	Wood	6,140-6,200	Larsen, 1974
ISGS-260	4,890 ± 75	Wood	5,650	Larsen, 1974
ISGS-259	4,740 ± 75	Wood	5,520-5,550	Larsen, 1974
W-3246	4,690 ± 200	Wood	5,360-5,470	Gutschick & Gonsiewski, 1976
ISGS-959	4,690 ± 90	Shell	5,360-5,470	This paper
ISGS-961	4,550 ± 70	Shell	5,300-5,320	This paper
ISGS-266	4,300 ± 75	Shell	4,930-4,890	Larsen, 1974
ISGS-286	4,185 ± 75	Peat	4,870	This paper
ISGS-288	3,950 ± 75	Organic sand	4,510	Larsen, 1974
ISGS-318	3,800 ± 75	Organic sand	4,140-4,240	This paper
W-3243	3,710 ± 200	Wood	4,110	Gutschick & Gonsiewski, 1976
ISGS-265	3,275 ± 75	Organic sand	3,590	Larsen, 1974
ISGS-217	3,130 ± 100	Peat	3,440	Larsen, 1974
ISGS-218	2,980 ± 130	Peat	3,220-3,250	Larsen, 1974
ISGS-225	2,280 ± 75	Peat	2,730	Larsen, 1974
ISGS-224	2,275 ± 75	Peat	2,730	Larsen, 1974
ISGS-356	1,750 ± 75	Organic silt	1,740	This paper
ISGS-278	1,580 ± 75	Wood	1,550	This paper
ISGS-297	1,450 ± 75	Peat	1,400	Larsen, 1974
ISGS-333	1,320 ± 75	Organic silt	1,300	This paper
ISGS-285	1,195 ± 75	Organic silt	1,160-1,180	This paper
ISGS-169	1,165 ± 75	Peat	1,130-1,150	Hester & Fraser, 1975
ISGS-284	1,105 ± 75	Organic silt	1,070-1,090	Larsen, 1974
ISGS-350	1,015 ± 75	Organic silt	985	This paper
ISGS-325	875 ± 75	Organic silt	860	This paper
ISGS-279	790 ± 75	Organic silt	760	This paper
ISGS-206	780 ± 75	Organic silt	730-750	This paper
ISGS-253	765 ± 75	Peat	730-750	This paper
ISGS-168	715 ± 75	Peat	710	Hester & Fraser, 1973
ISGS-263	560 ± 75	Organic sand	575	This paper
ISGS-182	540 ± 75	Peat	565	Hester & Fraser, 1973
ISGS-289	500 ± 75	Organic sand	545	This paper
ISGS-367	440 ± 75	Wood	520	This paper
ISGS-351	385 ± 75	Wood	500	This paper

* ISGS, Illinois State Geological Survey; W, U.S. Geological Survey; I, Isotopes, Inc.

An unnamed transgression that began between 6,350 and 5,500 B.P. ended the Chippewa low stage in southern Lake Michigan about 6,350 B.P. Cowan (1978) also recognized a transgressive event about this time near Sault St. Marie, Ontario. The exact altitude reached by this rise in lake level is unknown. This level was followed by a lower or stable level between 5,500 and 4,700 B.P. A rise in water level to the first peak of the Nipissing stage began about 4,700 B.P. and by 4,750 B.P., marshes at 179 m were inundated. A maximum Nipissing level at about 183 m was attained about

4,500 B.P. at Michigan City, Indiana, but this level was of relatively short duration, as shown by peat formation at 178.2 m dated at $4,185 \pm 75$ B.P. at Chicago. This level represents the Nipissing I phase of the Nipissing-stage Great Lakes. Stream incision below 179 m between 4,300 and 4,000 B.P. indicates that lake level dropped below this altitude. A second transgression between 4,000 and 3,800 B.P. left a reworked terrace surface at Barnes Creek, Wisconsin. Hough (1958) and Willman (1971) suggested that a single Nipissing-stage level of the upper Great Lakes existed for 1,000 to 1,500 years. Dated landforms from southern Lake Michigan define two separate high events separated by a period of low lake level between 4,200 and 4,000 B.P. The Nipissing I phase reached an altitude of 183 m in southern Lake Michigan, whereas the Nipissing II phase reached 180.5 m. Neither of the two high phases lasted more than 500 years.

Previous models attributed the Nipissing levels to the closure of northern outlets by differential uplift, which caused a higher lake level graded to the southern outlets at Chicago and Port Huron. Episodic incision of outlet channels into the Port Huron moraine in southern Lake Huron is claimed by Hough (1958) to have caused an equally rapid drop in level to the Algoma-stage level. Uplift and incision are clearly factors here, but the fluctuating nature of the Nipissing-stage levels, to say nothing of an earlier fluctuation between 6,350 and 5,000 B.P., points to significant climatic effects on the hydrologic system.

The Algoma stage in southern Lake Michigan began with the drop in lake level from the Nipissing II high stand at 180.5 m to about 178.2 m by 3,800 B.P. Stabilization of lake level near this altitude is documented by beach ridges near Carol Beach, Wisconsin that range in altitude from 179 m to 180 m. A rapid drop in level to near or below the present lake level at about 3,000 B.P. marks the end of this stage. When viewed in conjunction with Nipissing-stage lake levels, the rapid fall in lake level marking the end of the Algoma stage also suggests possible paleoclimatic influences.

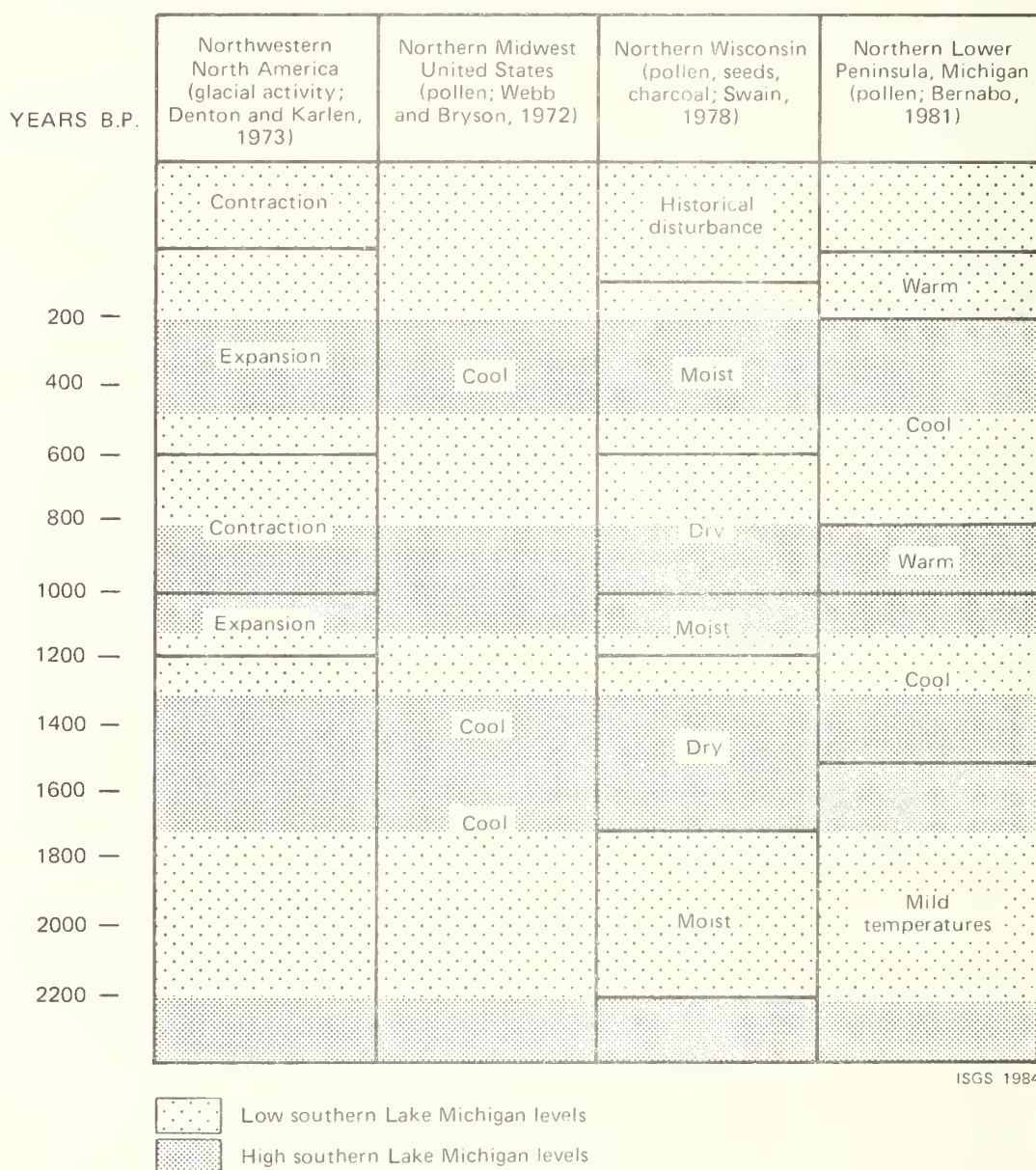
A post-Algoma low phase between 3,000 and 1,600 B.P. is indicated by the noticeable lack of alluvial terraces of this age found in the adjacent stream systems and by the inundation of an extensive area of the central beach-ridge complex by post-1,150 B.P. marsh development. After 1,600 B.P., lake levels rose as much as 1 to 2 m above the present; this period is documented by the formation of extensive beach ridges and dunes at Illinois Beach State Park, where beach deposits underlying regressive beach or dune deposits are higher than deposits associated with the present active beaches (Fraser and Hester, 1974). The combined stratigraphic record of alluvial terraces and marshes gives a more detailed account of lake level fluctuations. During the period 1,700 to 1,250 B.P., alluviation of streams was common. Flood plains were built to at least 1.5 m above present stream levels. Alluviation during a similar time period has been noted near Saginaw Bay, Michigan (Speth, 1972), but a potential difference in uplift between these two areas makes correlation difficult.

An extended period of low lake level, 1,250 to 950 B.P., documented by peat deposits 2 m below the present lake level, was followed by a period characterized by flooding of marshes and stream alluviation (950 to 700 B.P.). A similar period of lake transgression identified on the basis of dune morphology along the south shore of Lake Michigan was proposed by Olson (1958). Transgressive beach stratigraphy of similar age has also been reported by McPherron (1967) at the Straits of Mackinac, but at this location differences in active isostatic rebound complicate interpretation. Lake level dropped below 177 m between 700 and 450 B.P. Peat formation began at

that time, and regressive dunes formed on the 180-m terrace south of Kenosha (fig. 1, section 2). The dune deposits suggest rapid exposure of nearshore sediments to onshore winds during a regression of the lake. Olson (1958) also identified a lower lake level at this time on the basis of regressive dune development along the south shore of Lake Michigan. Another period of transgression reached a maximum between A.D. 1,500 and the beginning of the 19th century.

The episodic pattern of late Holocene lake level change suggests an important linkage between lake levels and paleoclimatic variations in the upper Great Lakes basin. Table 2 is a comparison of climatic changes during the past 2,200 years at various locations in North America (adapted from Swain, 1978). Similar lake levels and temperature and moisture changes in northern Wisconsin and Michigan over the past 1,200 years suggest probable variation in the water budget of the upper Great Lakes over this same period. A general correlation appears to exist among periods of glacial ex-

Table 2. Comparison of climatic changes during the last 2,000 years with southern Lake Michigan levels



pansion, cool and moist climatic episodes in the upper Great Lakes region, and periods of high lake level. Conversely, periods of low lake level coincide approximately with periods of contraction of certain Alaskan and Swedish glaciers and locally warm and dry climatic periods. A period of apparent glacier contraction in the northern hemisphere during the past two centuries also seems to correlate, although less directly, with a period of low lake levels and milder temperatures in the Great Lakes region.

CONCLUSIONS

Radiocarbon dated stratigraphy providing new evidence for fluctuating levels of Lakes Michigan and Huron during the middle and late Holocene indicates that models showing stabilization of regimes over the past 3,000 years (Leverett and Taylor, 1915; Hough 1958, 1963) must be revised. The interpretation presented in this paper provides an alternative to the model that attributes the Nipissing and Algoma stages of the lake to the episodic erosion of outlets. Although the importance of isostatic rebound and outlet changes is acknowledged, paleoclimatic changes during the Holocene have clearly had significant effects on the levels of Lake Michigan and Lake Huron (Larsen, 1973, 1974; Fraser et al., 1975).

On the basis of this study, the following conclusions can be made:

- A mesoscale of paleoenvironmental change (on the order of centuries) is discernible from a detailed study of postglacial deposits surrounding the Great Lakes. This change provides a clue to mesoscale hydrologic trends, a clue that cannot be derived from statistical analyses of the existing historic data.

- Discrepancies in altitude are apparent between the Nipissing and Algoma levels of southern Lake Huron and those of southern Lake Michigan. This condition leads us to question the accuracy of Leverett and Taylor's (1915) "zone of horizontality" upon which absolute altitudes for lake stages were based. The ideas presented by Clark and Persoage (1970) for historic uplift over the basin during the past century provide a more representative concept than do "hinge lines." Although the concept has still not been fully explored for the Lake Michigan basin, it seems reasonable to conceive of rebound as a continuing process that had far more effect on lake levels during the past 5,000 years than has been previously recognized. Nipissing and Algoma stages of the lake should therefore not be defined by fixed altitudes nor should landforms be classified solely on the basis of altitude. The differences noted between altitudes of beach features at Kenosha and Port Huron indicate that significant isostatic uplift occurred in southern Lake Michigan during this period. For the purpose of conceptualization, it is useful to extend the isostatic rebound models of Farrand (1962) and Andrews (1970) at least as far south as Kenosha. The Nipissing and Algoma stages in southern Lake Michigan, as well as the later changes documented for the past 2,000 years, appear to be climate-related fluctuations superimposed upon isostatic rebound of the basin.

Evidence reported in this study indicates that erosion of the St. Clair River outlet of Lake Huron was not the sole determinant of the Nipissing and Algoma stage levels. Although the threshold altitudes of outlets are clearly key factors, our knowledge of Holocene climatic changes indicates that climatic variations are a more logical explanation for relatively rapid changes in lake level.

REFERENCES

- Andrews, J. T., 1970, Present and postglacial rates of uplift for glaciated northern and eastern North America derived from postglacial uplift curves: *Canadian Journal of Earth Sciences*, v. 7: p. 703-775.
- Antevs, E., 1955, Geologic-climatic dating in the west: *American Antiquity*, v. 20, p. 317-335.
- Baker, F. C., 1920, The life of the Pleistocene or glacial period: University of Illinois Museum of Natural History, Contribution No. 7, 476 p.
- Barry, R. G., and R. J. Chorley, 1970, Atmosphere, weather and climate: New York, Holt Rinehart, Winston, Inc., 320 p.
- Benedict, J. B., 1973, Chronology of cirque glaciation, Colorado Front Range: *Quaternary Research*, v. 3, p. 584-599.
- Bretz, J. H., 1955, Geology of the Chicago region, Part II: The Pleistocene: Illinois State Geological Survey Bulletin 65, 132 p.
- Bernabo, J. C., 1981, Quantitative estimates of temperature changes over the last 2,700 years in Michigan based on pollen data: *Quaternary Research*, v. 15, p. 143-159.
- Clark, R. H., and N. P. Persoage, 1970, Some implications of crustal movement in engineering planning: *Canadian Journal of Earth Sciences*, v. 7, p. 628-633.
- Cowan, W. R., 1978, Radiocarbon dating of Nipissing Great Lakes events near Sault Ste. Marie, Ontario: *Canadian Journal of Earth Sciences*, v. 15, p. 2026-2030.
- Curry, R. R., 1969, Holocene climatic and glacial history of the central Sierra Nevada, California, in S. A. Schumm and W. C. Bradley [eds.], *United States contributions to Quaternary research: Geological Society of America Special Paper 123*, p. 1-47.
- Davis, M. B., 1969, Palynology and environmental history during the Quaternary period: *American Scientist*, v. 57, p. 317-332.
- Denton, G. H., and W. Karlen, 1973, Holocene climatic variations—their pattern and possible cause: *Quaternary Research*, v. 3, p. 155-205.
- Dorr, J. A., and D. F. Eschman, 1970, *Geology of Michigan*: Ann Arbor, University of Michigan Press, 476 p.
- Evenson, E. B., W. R. Farrand, and D. F. Eschman, 1976, Greatlakean Substage: a replacement for Valderan Substage in the Michigan Basin: *Quaternary Research*, v. 6, p. 411-424.
- Farrand, W. R., 1962, Postglacial uplift in North America: *American Journal of Science*, v. 260, p. 181-199.
- Fraser, G. S., and N. C. Hester, 1974, Sediment distribution in a beach ridge complex and its significance in land use planning: Illinois State Geological Survey Environmental Geology Note 67, 26 p.
- Fraser, G. S., C. E. Larsen, and N. C. Hester, 1975, Climatically controlled high lake levels in the Lake Michigan and Lake Huron basins: *Anais. Academia Brasileira Ciencias*, v. 47, p. 51-66 (Suplemento).
- Goldthwait, J. W., 1908, A reconstruction of water planes of the extinct glacial lakes in the Lake Michigan basin: *Journal of Geology*, v. 16, p. 459-476.
- Goldthwait, R. P., 1966, Evidence from Alaskan glaciers of major climatic changes, in J. S. Sawyer [ed.], *World climate from 8,000 to 0 B.C.*: London, Royal Meteorological Society, p. 40-53.
- Gutschick, R. C., and J. Gonsiewski, 1976, Coastal geology of Mt. Baldy, Indiana Dunes National Lakeshore, South End of Lake Michigan: *Fieldtrip Guidebook, North Central Section, Geological Society of America*, p. 40-90.
- Hester, N. C., and G. S. Fraser, 1973, Sedimentology of a beach ridge complex and its significance in land use planning: Illinois State Geological Survey Environmental Geology Note 63, 24 p.
- Horton, R. E., 1927, *Hydrology of the Great Lakes; Report of the Engineering Board of Review of the Sanitary District of Chicago on the lake lowering controversy and a program of remedial measures*: Chicago, City of Chicago.
- Hough, J. L., 1955, Lake Chippewa, a low stage of Lake Michigan indicated by bottom sediments: *Geological Society of America Bulletin*, v. 66, p. 957-68.
- Hough, J. L., 1958, *Geology of the Great Lakes*: Urbana, University of Illinois Press, 313 p.

- Hough, J. L., 1963, The prehistoric Great Lakes of North America: *American Scientist*, v. 51, p. 84-109.
- Larsen, C. E., 1973, Prehistoric levels of Lake Michigan-Huron: their potential in shoreland planning: *Proceedings of Shoreland Planning Conference*, Chicago, Lake Michigan Federation.
- Larsen, C. E., 1974, Late Holocene lake levels in southern Lake Michigan, *in* C. Collinson [ed.], *Coastal geology, sedimentology, and management; Chicago and the Northshore: Illinois State Geological Survey Guidebook Series 12*, p. 39-49.
- Leverett, F., and F. B. Taylor, 1915, The Pleistocene of Indiana and Michigan and the history of the Great Lakes: *U.S. Geological Survey Monograph 53*, 529 p.
- Lewis, C.F.M., 1969, Late Quaternary history of lake levels in the Huron and Erie basins: *Proceedings of the 12th Conference of Great Lakes Research*, Ann Arbor, International Association for Great Lakes Research, p. 250-270.
- Lewis, C.F.M., 1970, Recent uplift of Manitoulin Island, Ontario: *Canadian Journal of Earth Sciences*, v. 7, p. 665-675.
- Liu, P., 1970, Statistics on Great Lakes levels: *Proceedings of the 13th Conference of Great Lakes Research*, Ann Arbor, International Association for Great Lakes Research, p. 360-368.
- Olson, J. S., 1958, Lake Michigan Dune Development 3. Lake Level, Beach and Dune Oscillations: *Journal of Geology*, v. 66, p. 473-483.
- McPherron, A., 1967, The Juntunen site and the Late Woodland prehistory of the upper Great Lakes area: *University of Michigan, Museum of Anthropology Anthropological Paper No. 30*, 306 p.
- Miller, B. B., P. F. Karrow, and L. L. Kalas, 1979, Late Quaternary mollusks from Glacial Lake Algonquin, Nipissing, and transitional sediments from Southwestern Ontario, Canada: *Quaternary Research*, v. 11, p. 93-112.
- Ralph, E. K., H. N. Michael, and M. C. Han, 1973, Radiocarbon dates and reality: *MASCA Newsletter*, Philadelphia, University of Pennsylvania Museum, 20 p.
- Sander, P., 1969, Kenosha sand dunes: *Wisconsin Academy Review*, v. 16, p. 1-4.
- Speth, J. D., 1972, Geology of the Schultz site, *in* J. Fitting [ed.], *The Schultz site: University of Michigan Museum of Anthropology Memoir No. 4*, p. 53-75.
- Swain, A. M., 1978, Environmental changes during the past 2,000 years in north central Wisconsin: Analysis of pollen, charcoal, and seeds from varved lake sediments: *Quaternary Research*, v. 10, p. 55-68.
- Ten Brink, N. W., 1974, Glacio-isostasy: new data from west Greenland and geophysical implications: *Geological Society of America Bulletin*, v. 85, p. 219-228.
- Thwaites, R., 1902, Collections of the State Historical Society of Wisconsin, XVI: Madison, State Historical Society of Wisconsin.
- Vander Leest, B., and D. B. Halmo, 1980, Conservation archaeology in southern Wisconsin: The Barnes Creek Site: *University of Wisconsin-Parkside Applied Urban Field School Monograph no. 1*, 230 p.
- Walcott, R. J., 1970, Isostatic response to loading of the crust in Canada: *Canadian Journal of Earth Sciences*, v. 7, p. 716-725.
- Washburn, A. L., and M. Stuiver, 1962, Radiocarbon-dated postglacial delevelling in northeast Greenland and its implication: *Arctic*, v. 15, p. 66-73.
- Webb, T., and R. A. Bryson, 1972, Late and postglacial climatic change in the northern Midwest, USA: Quantitative multivariate statistical analyses, *Quaternary Research*, v. 2, p. 70-115.
- Willman, H. B., 1971, Summary of the geology of the Chicago area: *Illinois State Geological Survey Circular 460*, 77 p.
- Willman, H. B., and J. C. Frye, 1970, Pleistocene stratigraphy of Illinois: *Illinois State Geological Survey Bulletin 94*, 204 p.
- Winkler, E. M., 1962, Radiocarbon ages of postglacial lake clays near Michigan City, Indiana: *Science*, v. 137, p. 528-529.
- Wright, H. E., 1966, Stratigraphy of lake sediments and the precision of the paleoclimatic record, *in* J. S. Sawyer [ed.], *World climate from 8,000 to 0 B.C.*: London, Royal Meteorological Society, p. 84-97.
- Wright, H. E., 1968, History of the prairie peninsula, *in* R. E. Bergstrom [ed.], *The Quaternary of Illinois: University of Illinois College of Agriculture Special Publication 14*, p. 78-88.

APPENDIX. Dated stratigraphy

- 1 Kenosha, Wisconsin — NW1/4 SW1/4 Sec. 8, T 1 N, R 23 E**

178.1–180 m	Crossbedded nearshore sand
178–178.1 m	Black organic clay containing branches and in situ stumps
	paleosol: (7,340 ± 75 B.P.)
	wood: (6,340 ± 300 B.P.)
	wood: (5,315 ± 75 B.P.)
177–178 m	Gray glacial till
- 2 Kenosha, Wisconsin — NE1/4 NW1/4 NW1/4, Sec. 17, T 1 N, R 23 E**

180–183 m	Crossbedded eolian sand
179.9–180 m	Black organic sand (paleosol) (780 ± 75 B.P.)
177–179.9 m	Cross-bedded nearshore sand
- 3 South Kenosha, Wisconsin — NW 1/4 SW1/4 Sec. 17, T 1 N, R 23 E**

179.9–180 m	Black organic sand
179.0–179.9 m	Low-angle, crossbedded nearshore sand
178.2–179 m	Ripple-bedded nearshore sand
178.2 m	Wood fragments (6,350 ± 140 B.P.)
177–178.2 m	Ripple-bedded nearshore sand
- 4 Barnes Creek, Wisconsin — NW1/4 SE1/4 NE1/4 Sec. 19, T 1 N, R 23 E**

180–180.2 m	Black organic sand
179.8–180 m	Brown, organic, silty sand containing shells
179.4–179.8 m	Gray, organic silty sand
179.3–179.4 m	Tan, fine to medium sand
179–179.3 m	Black, organic, silty sand (3,950 ± 120 B.P.)
178–179 m	Gray, clayey till and lacustrine clay/silt
- 5 Barnes Creek, Wisconsin — SE1/4 SE1/4 NE1/4 Sec. 19, T 1 N, R 23 E**

180.4–181.0 m	Tan, fine-grained eolian sand
180.1–180.4 m	Black, organic sand (paleosol) (560 ± 75 B.P.)
179.8–180.1 m	Tan, well-sorted, fine to medium nearshore sand
179.7–179.8 m	Gray, gravelly silty clay
179.3–179.7 m	Gray, gravelly sand
179.3 m	Organic zone with roots and branches (4,740 ± 75 B.P.)
178.9–179.3 m	Gray organic silt with gastropods and roots (4,890 ± 75 B.P.)
178.9 m	Organic zone with roots and branches
178.4–178.4 m	Gray, gravelly sand with wood (5,500 ± 75 B.P.)
178–178.3 m	Gray, clayey silt (very compact)
- 6 Barnes Creek, Wisconsin — N1/2 SE1/4 NE1/4 Sec. 19, T 1 N, R 23 E**

180.2–180.4 m	Brown, fine to medium sand
180.1–180.2 m	Dark brown organic sand (paleosol) (875 ± 75 B.P.)
179.9–180.1 m	Tan, fine to medium sand
179.8–179.9 m	Dark brown organic sand (paleosol) (3,800 ± 75 B.P.)
179.2–179.8 m	Tan, fine to medium sand with cobble lenses
177.5–179.2 m	Contorted gray lacustrine silts

7 Barnes Creek, Wisconsin — NW1/4 SE1/4 NE1/4 Sec. 19, T 1 N, R 23 E

179-179.8 m	Peat (1,450 ± 75 B.P.)
178.8-179 m	Tan, fine to medium sand

8 Carol Beach, Wisconsin — S1/4 SE1/4 SE 1/4 Sec. 30, R 23 E

179.7-180 m	Dark gray organic silt
179.4-179.7 m	Peat (765 ± 75)
179.2-179.4 m	Black organic silt with tan sand layers
179.1-179.2 m	Black, organic silty sand
179.0-179.1 m	Black organic silt
178.9-179.0 m	Black organic sand (3,275 ± 75 B.P.)

9 Fossland Park, Illinois — SW1/4 NE1/4 NW1/4 Sec. 10, T 46 N, R 12 E

184.75-185.2 m	Brown silty fine sand (top of terrace)
184.7-184.75 m	Dark brown organic silty sand (1,015 ± 75 B.P.)
184.2-184.7 m	Brown silty sand
184.1-184.2 m	Black organic silt (paleosol) (1,320 ± 75 B.P.)
183.9-184.1 m	Gray-brown, oxidized sandy silt
183.8-183.9 m	Gray, clayey silt containing carbonized roots
183.5-183.8 m	Gray-brown fine to medium sand

9A Fossland Park, Illinois — S1/2 SW1/4 SW1/4 Sec. 3, T 46 N, R 12 E

184.9-185.2 m	Dark-gray silty medium sand
184.8-184.9 m	Gray-brown oxidized silty medium sand
184.4-184.8 m	Dark-gray silty medium to coarse sand
184.2-184.4 m	Gray-brown, oxidized, silty, medium sand
184.0-184.2 m	Gray, clayey silty sand containing branches (440 ± 75 B.P.)

10 Winthrop Harbor, Illinois — NE1/4 SE1/4 NW1/4 Sec. 10, T 46 N, R 33 E

178.7-179 m	Peat
178.45-178.7 m	Gray organic silt
178.35-178.45 m	Gray clayey silt
178.35 m	Wood
178.25-178.35 m	Brown organic silt
178.25 m	Wood
178.2-178.25 m	Brown organic sandy silt
178.15-178.2 m	Peat (3,130 ± 100 B.P.)
178.0-178.15 m	Black organic sand
178.95-178.0 m	Peat (2,980 ± 130 B.P.)
177.8-178.95 m	Black organic sand

11 Kellogg Creek, Illinois — NW1/4 SW1/4 NW1/4 Sec. 15, T 46 N, R 12 E

184.3-185.3 m	Tan, fine to medium sand (top of terrace)
183.2-184.3 m	Gray, silty fine to medium sand with wood at 183.5 m (385 ± 75 B.P.)

**11A Kellogg Creek, Illinois — NW1/4 SE1/4 NW1/4 Sec. 15,
T 46 N, R 12 E**

185.08-185.3 m	Dark brown silty fine sand
184.95-185.08 m	Tan, medium sand
184.70-184.95 m	Dark brown organic silt (paleosol 790 ± 75 B.P.)
184.09-184.70 m	Light brown fine sandy silt
183.0-184.09 m	Tan, fine to medium sand

**11B Kellogg Creek, Illinois — NW1/4 SE1/4 NW1/4 Sec. 15,
T 46 N, R 12 E**

183.49-184.44 m	Gray fine sandy silt
183.19-183.49 m	Red-brown medium to coarse sand
183.09-183.19 m	Gray fine sandy silt
182.98-183.09 m	Red-brown fine gravel lens
182.80-182.98 m	Gray fine sandy silt
182.65-182.80 m	Red-brown crossbedded coarse sand
182.0-182.65 m	Brown medium to coarse sand (1,580 ± 75 B.P.)

12 Kellogg Creek, Illinois — SE1/4 SE1/4 NW1/4 Sec. 15, T 46 N, R 23 E

179.7-180.1 m	Gray-brown, silty, fine to medium sand
179.6-179.7 m	Red-brown fine sandy silt (oxidized)
179.55-179.6 m	Tan silty fine sand
179.5-179.55 m	Gray fine sandy silt
179.4-179.5 m	Tan silty fine to medium sand
179.37-179.4 m	Gray, fine sandy silt
179.3-179.37 m	Tan, silty fine to medium sand
179.2-179.3 m	Black organic silt (1,105 ± 75 B.P., 1,195 ± 75 B.P.)
179.1-179.2 m	Black organic medium sand
178.79-1 m	Tan Fe-stained medium sand (beach ridge)

13 Camp Logan, Illinois — NE1/4 NE1/4 SE1/4 Sec. 15, T 46 N, R 23 E

177.7-178 m	Black sandy organic silt
177.4-177.7 m	Orange limonitic silt
177.2-177.4 m	Gray organic silt with traces of limonite
177.0-177.2 m	Gray organic silt
176.95-177.0 m	Peat (2,280 ± 75 B.P.)
176.9-176.95 m	Gray organic clayey silt
176.8-176.9 m	Peat (2,275 ± 75 B.P.)
176.7-176.8 m	Black organic sand
176.6-176.7 m	Gravelly sand

**14 Shiloh Boulevard, Illinois — SW1/4 SE1/4 NE1/4 Sec. 22,
T 46 N, R 23 E**

177-178 m	Fill
175.5-177 m	Gray organic clayey silt
174.7-175.5 m	Peat (1,165 ± 75 B.P.)
174.5-174.7 m	Gravelly sand

15 Bull Creek, Illinois — NE1/4 SE1/4 SW1/4 Sec. 28, T. 46 N, R 12 E

187.8–188.7 m	Gray-brown gravelly silt
187.6–187.8 m	Gray-brown silt
187.5–187.6 m	Dark-gray organic silt (paleosol 1,750 ± B.P.)
187–187.5 m	Gray-brown sandy silt

16 Wadsworth Road, Illinois — NW1/4 SW1/4 SE1/4 Sec. 27, T 46 N, R 12 E

177.7–178 m	Gray organic clayey silt
177.6–177.7 m	Gray organic clay
177.5–177.6 m	Gray clay with gastropods
177.3–177.5 m	Fine to medium sand
177–177.3 m	Clay
176.7–177 m	Organic clay
176.3–176.6 m	Peat (715 ± 75 B.P.)
176–176.3 m	Organic clay

17 Wadsworth Road, Illinois — NE1/4 SW1/4 SE1/4 Sec. 27, T 46 N, R 12 E

177.9–178 m	Organic clayey silt
177.4–177.9 m	Clayey silty sand
177.3–177.4 m	Peat
176.1–177.3 m	Nonorganic clay silt
175.8–176.1 m	Peat (540 ± 75 B.P.)
175.2–175.5 m	Gravelly sand

Composite Section North Shore Channel, Chicago River — NE1/4 NW1/4 SW1/4 Sec. 12, T 40 N, R 13 W

178.4–181.4 m	Clayey silt with bricks, bottles and shells
178.2–178.4 m	Dark-gray silty clay
178.1–178.1 m	Peat (4,185 ± 75)
177.8–178.1 m	Gray silty clay with shells (top 30 cm oxidized) (4,690 ± 90, 4,550 ± 70, and 4,300 ± 75 B.P.)
177.7–177.8 m	Tan, gravelly sand with <i>Unios</i> on surface
177.5–177.7 m	Gray-brown gravelly sand
177.0–177.3 m	Silt at this approximate location and elevation contained branches (5,370 ± 200 B.P., 5,580 ± 70 B.P.) when described by Baker (1920).

Central Avenue Section, Michigan City, Indiana

184.5–190 m	Crossbedded eolian sand
182.5–184.5 m	Crossbedded eolian sand (paleosol 3,710 ± 200 B.P.)
182.2–182.5 m	Oxidized gravelly sand
178.0–182.2 m	Very pale brown, crossbedded medium-grained nearshore sand
177.7–178 m	Gray, organic clay with wood (5,475 ± 250 B.P.)
177.1–177.7 m	Tan, lacustrine sand
176.0–177.1 m	Gray, carbonaceous, fossiliferous clay (4,690 ± 200 B.P.)
176.0 m	Compressed wood (6,350 ± 200 B.P.)
175.7–176.0 m	Pale brown, pebbly clay

LAKE MICHIGAN STUDIES

1. EGN 30 – Preliminary Stratigraphy of Unconsolidated Sediments from the Southwestern Part of Lake Michigan. 1970.
2. EGN 32 – Distribution of Major, Minor, and Trace Constituents in Unconsolidated Sediments from Southern Lake Michigan. 1970.
3. EGN 35 – Stratigraphy of Unconsolidated Sediments in the Southern Part of Lake Michigan. 1970.
4. EGN 37 – Distribution of Arsenic in Unconsolidated Sediments from Southern Lake Michigan. 1970.
5. EGN 39 – Phosphorus Content in Unconsolidated Sediments from Southern Lake Michigan. 1970.
6. EGN 41 – Trace Element and Organic Carbon Accumulation in the Most Recent Sediments of Southern Lake Michigan. 1971.
7. EGN 44 – Distribution of Mercury in Unconsolidated Sediments from Southern Lake Michigan. 1971.
8. EGN 47 – High-Resolution Seismic Profiles and Gravity Cores of Sediments in Southern Lake Michigan. 1971.
9. EGN 54 – Geologic Cross Sections Derived from Seismic Profiles and Sediment Cores from Southern Lake Michigan. 1972.
10. EGN 58 – Depositional Patterns, Facies, and Trace Element Accumulation in the Waukegan Member of the Late Pleistocene Lake Michigan Formation in Southern Lake Michigan. 1972.
11. EGN 69 – Glacial Till under Lake Michigan. 1974.
12. EGN 74 – A Side-Scan Sonar Investigation of Small-Scale Features on the Floor of Southern Lake Michigan. 1975.
13. EGN 76 – Bluff Erosion, Recession Rates, and Volumetric Losses on the Lake Michigan Shore in Illinois. 1976.
14. EGN 84 – Late Quaternary Sediments of Lake Michigan. 1978.
15. EGN 93 – Land Resources for Beach Nourishment along the Illinois Shore of Lake Michigan. 1981.
16. EGN 97 – Evaluation of Lake Michigan Nearshore Sediments for Nourishment of Illinois Beaches. 1981.
17. EGN 112 – A Stratigraphic Study of Beach Features on the Southwestern Shore of Lake Michigan: New Evidence of Holocene Lake Level Fluctuations. 1985.

